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ABSTRACT

Major concepts can help create thinking frameworks that are powerful enough to make additional input more meaningful. As a result, the content is richer, more diverse, and more widely applicable. This set of concept papers was produced because concepts are not uniformly understood by practitioners. Each is designed to introduce a concept and to define it in language that can be easily understood by teachers. Examples are included from contemporary curriculum, sample instructional objectives that are desirable for concept learning, and to provide sample test questions with a commentary as to their appropriateness for measuring concept learning. Concepts included are: (1) "Cause and Effect"; (2) "Change"; (3) "Cycle"; (4) "Energy-Matter"; (5) "Organism"; (6) "Population"; (7) "Force"; (8) "Interaction"; (9) "Order"; (10) "Quantification"; (11) "System"; (12) "Equilibrium"; (13) "Evolution"; (14) "Fundamental Entities"; (15) "Theory"; (16) "Model"; (17) "Perception"; (18) "Symmetry"; (19) "Field"; and (20) "Gradient." (CW)

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A Focus on Science Concepts

Science Concept Working Papers

by David C. Cox
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and the
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FOREWORD

A *Focus on Science Concepts* serves as a starting point for understanding the science concepts included in the Oregon Department of Education *Common Curriculum Goals for Science*. The concept papers featured in this document are not intended to be definitive statements about the concepts but are intended to serve as a common framework for discussions among teachers of science.

Each concept is presented in a **working** paper in order that the document can reflect the evolving development and understanding of the concepts in the K-12 science program of Oregon schools.

I encourage you to use this document when you engage in activities aimed at improving K-12 science education, a critical component of our total education program.

We are especially grateful to Dr. David Cox, principal author of this document, and others who added their wisdom and experience.

Verne A. Duncan
State Superintendent
of Public Instruction

Fall, 1989

Dear Reader:

Thank you for your interest in developing a concept-based science program in your school. Published by the Oregon Cadre for Assistance to Teachers of Science (OCATS), the following is a set of papers designed to help you begin your concept clarification and curriculum process.

Each paper has essentially the same sections: an introduction, a discussion of the concept, some sample instructional objectives, examples of good and bad evaluation, and a bibliography. Because you may wish to use the concept papers independently of each other, we have numbered the pages consecutively within each set (e.g., Concept #1 — 1.1, 1.2, 1.3, 1.4, 1.5, 1.6; Concept #2 — 2.1, 2.2, 2.3 . . .)

Remember that these are ***working*** papers. Although they have been reviewed and edited once, OCATS is still seeking input as to how they might be improved. Please use the last page in the booklet to inform us of any comments, suggestions, or questions you might have regarding the information in, or the style of, the papers. We plan to revise these papers in the summer of 1990 to reflect any reader responses.

Please note that the back of the response sheet (Suggested Improvements) has been preaddressed and postpaid for your convenience. You are encouraged to respond. Please fold the response sheet(s) (include extra pages if needed for your response), staple and mail.

Thanks again for your efforts on behalf of improving science instruction in Oregon. I hope you find these papers helpful in those efforts.

Raymond E. Thiess
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MAJOR SCIENCE CONCEPTS AND RECOMMENDED GRADE LEVEL FOR INSTRUCTION

			K-3	4-5	6-8	9-11
1.	(1.1)*	**Cause-Effect**	X	X	X	X
2.	(1.2)	**Change**	X	X	X	X
3.	(1.3)	**Cycle**	X	X	X	X
4.	(1.4)	**Energy-Matter**	X	X	X	X
5.	(1.5)	**Organism**	X	X	X	X
6.	(1.6)	**Population**	X	X	X	X
7.	(1.9)	**Force**		X	X	X
8.	(1.11)	**Interaction**		X	X	X
9.	(1.12)	**Order**		X	X	X
10.	(1.13)	**Quantification**		X	X	X
11.	(1.14)	**System**		X	X	X
12.	(1.7)	**Equilibrium**			X	X
13.	(1.8)	**Evolution**			X	X
14.	(1.10)	**Fundamental Entities**			X	X
15.	(1.15)	**Theory**			X	X
16.	(1.19)	**Model**			X	X
17.	(1.20)	**Perception**			X	X
18.	(1.24)	**Symmetry**			X	X
19.	(1.16)	**Field**				X
20.	(1.17)	**Gradient**				X
		Total additional concepts per category	0	5	8	6
		Total concepts per category	6	11	19	20

* Reference number is taken from the state of Oregon ***Science Common Curriculum Goals***, 1988 and the ***Science Comprehensive Curriculum Goals***, 1989.

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PREFACE*

"Knowing (unfortunately) is no longer the ability to summon up an organized view of some topic; it is the ability to recognize separate, discontinuous particles." Jacques Barzun, ***Basic Education; Issues, Answers & Facts,*** Vol. 3, No. 1, Fall 1987.

We can't study every natural phenomenon. In 1950, we couldn't even make it through our science texts. So we have this challenge; to identify what it is in science education that is of most worth.

But what is of most worth? In 1982 the National Science Teachers Association labeled it as scientific literacy (the ability to understand how science, technology and society influence one another and how this knowledge is used in everyday decision making). Interestingly, scientific literacy is not a yes or no proposition. It is something that continuously develops either with or without help. Learning science, therefore, should be a continuous process. Furthermore, developmental research is showing that this continuous process is more meaningful when, as Barzun states, it is the development of "an organized view of some topic."

Concepts and processes serve as organizers, unifying our approach to the learning of science. More important, they support the development of a scientifically literate population. That is why they serve as the basis of most of the Common Curriculum Goals for Science. That is also why it is to these organizers, then, that we need to turn our instructional attention.

Some teachers admit that they do not have a conceptual understanding of science. The real problem arises, however, when a teacher looks at a list of concepts and processes and says, "No problem. I already cover these." The problem is that most of us treat concepts as ends in themselves, not pointing out the qualities they have in common or the limitations they share in various contexts. Typically, we don't develop concepts as larger, logical organizers so that students can apply them not only in specific disciplines but in new situations as well.

Consider the concept of field. If the concept is developed only in terms of a magnetic field, for example, students would most likely think that the concept is useful only for explaining magnetism. If it is a generalized interaction, however, then when they see one object fall toward another, they might say, "Oh, it must be in its field or sphere of influence." To use a non-science example, if the U.S. makes a statement and several other countries respond, they can be said to be in our field or sphere of influence. Within the scientific community, a concept-like field is also used as a basis for making predictions. On the basis of those predictions (when tested in the laboratory), we develop our theories and models. Thus, concepts become useful for organizing our understanding and for explaining things; useful in developing our scientific literacy.

For the purposes of clarification, we can use learning psychology's definition of "concept" as an organizer for classes of events or objects. Concepts are usually identified by one- or two-word descriptors, such as cycle, force, equilibrium, or energy-matter. In the mind, many concepts are developed naturally because they are related to readily available physical objects. Most scientific concepts, however, deal with the organization of the physical world and are therefore invented. Invented concepts are much more difficult to structure because their organization is mentally constructed. To develop a student's understanding of these concepts requires a concerted effort on our part to change how we teach.

Since the construction of each concept requires a personal development process, teachers can not teach them, they must facilitate their development. Because multiple experiences with concepts are necessary for comprehension to develop, students must have different opportuni-

ties for input in multiple contexts, therefore new instructional strategies are indicated.

When we talk about concept learning, we are talking about things that teachers do in the classroom that enable students to develop these concepts at a more general level. Major concepts can create thinking frameworks that are so powerful that additional input becomes more meaningful. As a result, the content is richer, more diverse and more widely applicable. Concrete experiences, or hands-on learning, have been found especially useful in the initial stages of concept development, regardless of the age of the learner. Concept development does not occur by chance. You can't hope, as a teacher, that students will develop a concept. If you want that to happen, it has to be a planned part of instruction and the curriculum.

Because concepts are probably not uniformly understood in this new context, teachers may want to begin their own instructional development with this set of papers covering concepts included in the Oregon Department of Education's *Common Curriculum Goals for Science.* Each document is designed to introduce the concept and help define it in teacher language using examples from the contemporary curriculum; suggest sample instructional objectives that are desirable for concept learning; and provide sample test questions with a commentary as to their appropriateness for measuring concept learning.

These teaching aids are intended to serve only as a starting point for understanding the concepts. They are not intended to be definitive statements about the concepts. As a district begins the process of incorporating the Common Curriculum Goals for Science into its program, the papers will serve as a common framework for discussions among staff. They have been field-tested in workshop settings with groups of K-12 teachers and it has been found that these interdiscipline, cross grade-level discussions resulted in expanded and enriched definitions and understanding of the concepts.

We hope that you find these papers useful in helping you think about, discuss and revise your instructional approach. We encourage you to pursue continued growth in understanding and application of the ideas in these thought-provoking papers.

* *This Preface contains ideas excerpted from presentations made between 1984-87 by the author, David C. Cox, Assistant Professor, Portland State University.*

CAUSE-EFFECT

by David C. Cox
Portland State University

Science Concept Working Paper #1 **Fall 1989**

Introduction

People seem to have an overwhelming desire to know "what causes" observations of interest (e.g., lightning, disease, rain, shadows, rusting). Therefore, perhaps none of the major science concepts is more frequently applied than "cause-effect." Examples abound; among them are the rotation of the earth producing night and day, gravitational attraction causing things to fall to earth, excessive exposure to sunlight causing sunburn, oxidation creating "rust," and a lack of fuel causing an automobile engine to stop. This powerful explanatory and predictive idea is a key element in enhancing one's ability to understand both accumulated scientific knowledge and the dynamic world in which we live.

The Concept

The concept cause-effect operationally refers to those situations where one particular observation or event is always followed by another specific observation or event. By assigning causality in such cases, we are concluding that the first observation/event somehow brings about the second observation/event at a later time. Scientists regularly search for such cause-effect relationships, often between seemingly unrelated observations.

The term "always" in the description of a cause-effect situation is very important. In order for causality to be assigned, the two observations/events must always occur and always come in the same order. Since we can only document the past and present, all cause-effect relationships are tentative, waiting for continued confirmation or discrediting on the basis of later observations.

Cause-effect relationships are ideally established by means of carefully controlled experiments. These controlled experiments are necessary, since any one or more of a large number of suspected or unsuspected variables may be contributors to the observation of interest. In some situations, such as human disease, the ability to conduct various types of controlled studies is necessarily limited. This constraint sometimes results in the need for extended periods of time for identification of the relationship and/or less certainty regarding the findings.

The mechanism of the cause-effect linkage is often of interest. Once the cause-effect relationship has been established, the work to uncover the mechanism becomes more focused. Sometimes the mechanisms are able to be observed directly, while in other instances they are inferred and reported in the form of models.

The search for the cause of that group of diseases collectively known as malaria provides an example of both points previously made. For years, it was believed that swamp exhalations were the cause. Later the bite of the Anopheles mosquito was identified as the cause. Further study, however, found that the mosquitoes were the transfer agent for parasitic protozoans that were responsible for the illness.

While cause-effect relationships often involve single observations/events, multiple observations or events may also be involved. In addition, examples of cause-effect relationships can occur naturally, due to the intervention of humans, and/or between human technological creations.

One needs to be especially cautious about inappropriately assigning causality. Many events, conditions, phenomena, etc. can be found to have a large positive correlation coeffecient (in English, when one is present the other is always or almost always present). An example would be when students who are high achievers in science are also found to be high achievers in mathematics. It is tempting to infer that the success in science is a result of (caused by!) the achievement level in mathematics. Or said another way, it is tempting to speculate that one can increase science achievement simply by increasing the level of math achievement.

Causality is not established on the basis of correlational studies alone, even though these types of studies can assist in the identification of important variables to consider. As mentioned earlier, cause-effect relationships are identified by means of carefully controlled experiments, where the phenomena of interest can be observed with all potentially significant variables controlled.

Closely related major science concepts include change, cycle, energy-matter, equilibrium, evolution, field, force, gradient, interaction, model, order, perception, probability, replication, resonance, significance, system, and time-space.

Sample Instructional Objectives

From an instructional point of view, a concept takes on operational meaning when learner objectives are specified. The most meaningful concept development is likely to result from learning outcomes that address the concept in the most generalizable form possible. The sample objectives that follow are representative of a larger number that are particularly useful in promoting the understanding of and ability to appropriately apply the concept of cause-effect.

The objectives of this (lesson, unit, course, program) are for you to:	You will know you are making progress when you can:
1. Increase your understanding of the concept cause-effect.	1a. Operationally define cause-effect. 1b. List examples of cause-effect situations. 1c. Differentiate cause-effect, order, and cycle. 1d. Critique a given description of cause-effect. 1e.
2. Extend your ability to identify cause-effect relationships.	2a. When given appropriate information, determine if a cause-effect situation is possibly present. 2b. Describe the procedure for determining if a cause-effect situation exists. 2c.
3. Expand your ability to use the concept of cause-effect.	3a. When given appropriate data for an established cause-effect relationship, make predictions suitable for these data. 3b. When given data, demonstrations, lab experiences, etc., identify potential cause-effect observations. 3c.
4. Value cause-effect for its explanatory and predictive power.	4a. Choose to continue to develop your personal understanding of and ability to apply cause-effect. 4b. Value explanations and predictions based on cause-effect. 4c. Choose to attempt to identify cause-effect conditions when making observations. 4d.

Sample Test Questions

The sample evaluation items and their accompanying commentaries are intended to further illustrate the difference between concept-oriented learning outcomes involving the big ideas or major concepts in science and the more familiar content-oriented outcomes.

Question 1: ***Cause-effect relationships***

A. are established by the observation of one event being followed by another event.
B. are proven to be true by scientists before being accepted.
C. need to be established by the use of controlled experiments.
D. are found only in the physical sciences.
E. A and B

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Commentary: This concept-based question is concerned with the nature of cause-effect situations, and in particular with how appropriate examples are identified. Distractor "A" erroneously suggests that an observation of one event following another is adequate for establishing cause-effect. Choice "B" describes an impossible condition, "proven to be true," as a prerequisite for identifying examples of cause-effect. "D" incorrectly limits cause-effect to one category of phenomena. The correct choice is "C", and the item is suitable for use with Sample Objective 2.

Question 2: ***Which best illustrates the concept cause-effect?***

A. If observation X is made, then observation Y will follow.
B. Observations X and Y occur simultaneously.
C. If observation X is made, then observation Y will have been made either before or after X.
D. Whenever observation X is made, observation Y may be present.
E. If observation X is made, observation Y will follow, and if observation Y is made, X will follow.

Commentary: This concept-based item is concerned with the basic meaning of cause-effect. Operationally, causality is assigned if one observation is found to always follow the other in a series of experiments where possible contributing variables have been controlled. "A" is the correct answer, and the item is appropriate for use with Sample Objective 1.

Question 3: ***Which is believed to cause malaria?***

A. bacteria
B. swamp exhalations
C. parasitic protozoans
D. genetic predisposition
E. mosquitoes of the genus Anopheles

Commentary: This is NOT an example of a concept-based question. While the question deals with an example of a well known cause-effect relationship, the ability to respond correctly requires recall of previously-provided information regarding this particular category of diseases. A correct response provides little or no insight into the learner's level of understanding of the concept cause-effect.

Question 4: ***An educational study found that mathematics achievement was the best predictor of success in science.***

A. This is a good example of a study that established a cause-effect relationship.
B. There may be a cause-effect relationship present, but additional and different studies would be needed to determine this.
C. The findings probably represent a coincidence rather than a cause-effect relationship.
D. Based upon the results of this study, science achievement could be improved by improving mathematics achievement.
E. A and D

Commentary: This rather challenging concept-based question requires the learner to assess the findings of a simulated study relative to the possible application of cause-effect. Distractor "D" is especially interesting, since it represents a prediction based upon the assumption of a cause-effect relationship. The correct response is "B," and the item is appropriate for use with Sample Objectives 1 and 2.

For Further Information About Cause-Effect

CHANGE

by David C. Cox
Portland State University

Science Concept Working Paper #2 **Fall 1989**

Introduction

That which we call "change" is what adds dynamic diversity to our world. Change in varying degrees, rates, and kinds is everywhere around us. The seasons change, leaves change color, automobiles change speed, and even we change. Nothing escapes change!

Change, and especially its causes and results, is often the focus of scientific investigations, and regardless, is an integral part of our environment. The concept of change provides a powerful, widely applicable explanatory and predictive tool.

The Concept

When we speak of change, we are referring to the process of becoming different or something else. Becoming different can encompass an amazing variety of change, including change of state (e.g., liquid to solid, solid to gas, moving from Iowa to Oregon), the change of one or more physical characteristics (e.g., volume, density, texture, color, shape, temperature, pressure, heat content), and the host of changes that occur in a living thing as it is created, matures, and finally dies.

Examples of becoming something else are equally diverse. Radioactive elements transform themselves into other elements by virtue of nuclear change. Many life cycles (e.g., butterfly, frog) contain different types of organisms as part of the sequence of life events.

Closer to home for all of us is the use of change as a way of describing ourselves or those around us. Most of us have heard someone say, "You've changed since I saw you last." This could make reference to a difference in height, weight, hair style, personality, hair color, vocabulary, hair quantity, or any one of a large number of other physical and/or psychological characteristics that in combination are "us."

The rate at which change occurs plays a role in our awareness of it. Some changes are occurring so slowly, for example, that we recognize that change is taking place only over prolonged periods of time. Some examples would be the evolution of a species, movement of a glacier, and the burning out of a star. In other situations, the change can occur so rapidly that we have difficulty observing or describing the process. Some examples are the explosion of a firecracker, the speed of light, and the vibration of a tuning fork.

Some changes occur naturally, such as erosion, radioactive decay, and the maturation of living things; other changes are the result of human interaction. Examples of the latter would be farming, cloud seeding, and resource depletion. It is possible for some changes to be reversible (e.g., freezing water, movement up into the air), while others are "one way" (e.g., the passing of time, a life cycle).

Of special significance, because of the frequency of its use, is the classification of change into the categories of physical, chemical, and nuclear. Some traditional descriptions and examples of each category follow:

Physical Change: Change where the composition and identifying properties remain constant. Examples of physical changes are melting, freezing, evaporating, dissolving, and mixing.

Chemical Change: Change involving the formation of "new" substances with "new" properties. Examples of chemical changes are burning, rusting, and the electrolysis of water.

Nuclear Change: Changes within the nucleus of an atom that may or may not result in the formation of a new element(s). Examples are fusion, fission, and neutron absorption.

The concept of change is especially crucial for science educators. The rates of change in our natural and human-made environments, and the rate at which technology is being applied, are increasing. This increasing rate of change requires contemporary citizens to have to deal with (or cope with, plan for, understand, manage, accommodate, adapt to) change in a shorter time frame than ever before. Furthermore, this necessity to deal with increasing change impacts all aspects of their lives. In general, one's ability to deal effectively with change is a measure of one's success in a contemporary society. To put the point forward more bluntly, an increasingly rapidly changing world becomes an increasingly complex and demanding environment for personal interaction and decision making.

One of the most important specific types of change for citizens to comprehend is that known as exponential growth. While this aspect of change has been a focal point of many discussions regarding fossil fuel resource depletion, it has potentially staggering implications in a wide range of areas, such as population growth, resource depletion, and food supply requirements.

Many other major science concepts are closely related to change. Among these concepts are cause-effect, equilibrium, evolution, field, force, gradient, interaction (change is often cited as evidence of interaction), and matter-energy.

In summary, change is the process of becoming different or something else. The process can occur at a variety of speeds, and the rate can even vary during the process. Some change is reversible, while other is not. Change is often categorized into the major groups of chemical, physical, or nuclear. The mechanism of change is often a focus of scientific investigation.

Sample Instructional Objectives

From an instructional point of view, a concept takes on operational meaning when learner objectives are specified. The most meaningful concept development is likely to result from learning outcomes that address the concept in the most generalizable form possible. The sample objectives that follow are representative of a larger number that are particularly useful in promoting the understanding of and ability to appropriately apply the concept of change.

The objectives of this (lesson, unit, course, program) are for you to:	You will know that you are making progress when you can:
1. Increase your understanding of the concept of change.	1a. Operationally define change. 1b. Differentiate change, evolution, interaction, and gradient. 1c. Critique a given definition of change. 1d.
2. Increase your ability to recognize change.	2a. Identify examples of change in your environment. 2b. Identify examples of change with different rates of change. 2c. List at least three tests that could be used to determine if change is occurring in a given situation. 2d
3. Improve your ability to quantify change.	3a. When given appropriate data, calculate the rate of change. 3b. When given appropriate data, construct a graph that illustrates change. 3c.
4. Extend your understanding of the factors that influence change.	4a. Identify at least three factors influencing a given change. 4b. Predict the effect relative to change of increasing or decreasing the magnitude of a given factor. 4c.

Sample Test Questions

The sample evaluation items and their accompanying commentaries are intended to illustrate the difference between concept-oriented learning outcomes involving the big ideas or major concepts in science and the more familiar content-oriented outcomes.

Question 1: ***Which is NOT an example of change?***

A. a falling rock
B. burning wood
C. freezing liquid water to form solid ice
D. radioactive material
E. all are examples of change

Commentary: This concept-based test item requires students to recognize diverse examples of change (e.g., change of position, chemical change, physical change, nuclear change). The item is suitable for use in testing Sample Objective 2. The correct response is "E."

Question 2: ***Which is a characteristic of ALL change?***

A. occurs in a positive direction
B. rate is increasing
C. is reversible
D. something is becoming different or something else
E. is caused, directly, or indirectly, by the actions of humans

Commentary: This item, which is concept-based, requires students to thoughtfully evaluate a number of statements to determine which one is true for all types of change. The correct response is "D." This question is suitable for use in conjunction with Sample Objective 1.

Question 3: ***An automobile changes speed from 120 km/hr to 90 km/hr in 5.0 seconds. What was the acceleration of the automobile?***

A. - 30 km/hr
B. 24 km/hr/s
C. - 6.0 km/hr/s
D. 18 km/hr/s
E. none of these choices

Commentary: While this question may be in the "gray area" between a concept-oriented and topic-specific item, I would presently treat it as NOT appropriate for concept-based testing. In order to respond correctly, the student must recall the formula for calculating acceleration, be familiar with negative values for physical quantities, and deal with some rather atypical units. I believe prior experience with similar problems would be necessary in order for the student to knowingly respond correctly.

Question 4: ***A student defined "change" as when something becomes different. This description of change***

A. is a completely adequate statement describing the concept.
B. would be improved if "or something else" were added.
C. is inadequate because it doesn't have to be an object that changes.
D. is misleading because the change is not the before and after, but the process that is involved.
E. is inadequate, because the change may not be visible (e.g., too slow, too small) for an observer to detect.

Commentary: This higher level, concept-based item requires the student to evaluate a given definition and select the best evaluative statement. The preferred response is "B," and the question is appropriate for use with Sample Objective 1.

For Further Information About Change

CYCLE

by David C. Cox
Portland State University

Science Concept Working Paper #3 **Fall 1989**

Introduction

The idea "cycle" is widely used in both science and everyday affairs. While it is certainly debatable as to whether or not cycles are actually a fundamental part of the natural world, the identification of apparent cycles in nature has enabled humans to make many predictions with a very high degree of accuracy. Many believe that being able to successfully predict events is the fundamental basis for understanding a phenomenon. Cycle is truly a powerful concept having widespread application for both explanation and prediction.

The Concept

In the most straightforward sense, cycles are patterns identifiable because certain events or conditions appear to be repeated. This repetition can occur at regular intervals (rhythmic cycle), somewhat regular intervals, or widely variable intervals (nonrhythmic cycles). Examples of this cyclic behavior show tremendous diversity. Some are rather obvious, such as our pulse, ocean tides, phases of the moon or the eruption of "Old Faithful" geyser. Some of the other examples are less apparent; among these are the internal combustion engine, life cycles of a variety of organisms (e.g., insects, frogs, fish), the rock cycle (not the music, even though that's possible), water cycle, sunspot activity, comet sightings, population cycles, alternating electric current, and the nitrogen cycle. Other examples of cycles can be so subtle that there is serious debate as to whether or not they qualify. Examples of these are such possible cycles as business cycles, stock market prices, clothing fashions and educational reform movements.

In some instances, a cyclic phenomenon has the "object" of interest repeating a pattern of movement (e.g., pendulum, guitar string). In other situations, such as the life cycle of an organism, there is a repeating pattern of reproduction and development involving new generations of the organism. Other applications of the cycle concept have different forms of the same substance (e.g., water in the water cycle) involved. Space does not permit the identification of additional examples of this variation, but this diversity of qualifying phenomena is one of the attributes of cycle which makes it so rich and powerful.

The time required for a single cycle to be completed (recurrence of the identifying condition, event, position, etc.) is known as the "period." Periods can range from incredibly short (e.g., the beating of an atomic clock) to extremely long (e.g., the life cycle of stars). The period is a significant variable in the identification of cyclic phenomena, since our senses may require assistance to observe the extremely short periods and we may need to communicate between generations in order to observe the very long periods. The consistency of the period is also crucial to the identification of cyclic behavior. Cyclic phenomena with little variation in period are more easily identified and provide more precise predictions.

Whereas the period is the time interval between the repeating events or conditions used to identify the cyclic nature of an observed phenomenon, the frequency is a related measure specifying the number of event or condition intervals occurring per unit of time. Frequency and period are mathematical reciprocals of each other. For example, alternating electric current can be described as having a frequency of 60 cycles/second or a period of 1/60 second/cycle.

Cycles can change in a variety of ways (e.g., period) or even cease to be cycles. In order to better understand cyclic phenomena, efforts are made to identify the interacting elements (or components, stages, events) and the force(s) driving the cycle. Once these identifications have been made, it is possible to alter or stop an existing cycle if this action is deemed appropriate. Examples of such efforts would be breaking the cycle of crime, altering or breaking the life cycle of a disease-causing organism, and improving food supplies by means of altering life cycles of agricultural stock.

In summary, cycles are patterns identifiable because certain events or conditions are repeated. Cyclic phenomena can be rhythmic, somewhat rhythmic, or nonrhythmic. Cycles can be quantified in terms of period and/or frequency. Existing cycles can be altered or cease to exist either through natural events or due to the intervention of humans. Planned human intervention usually requires knowledge of the interacting elements within the cycle and the forces responsible for the observed behavior.

Sample Instructional Objectives

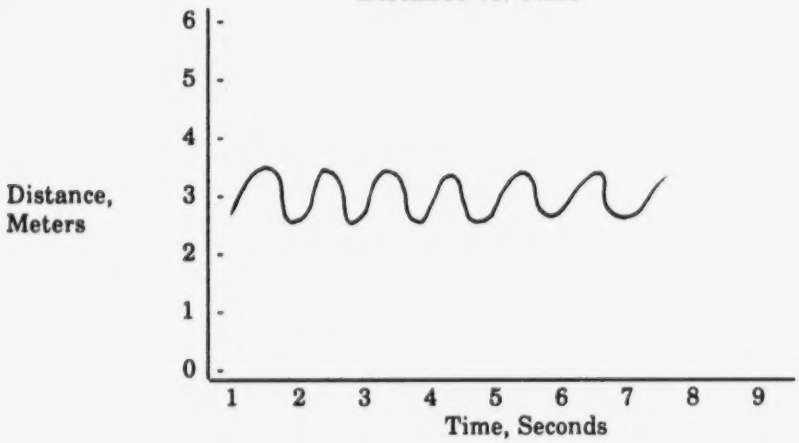
From an instructional point of view, a concept takes an operational meaning when learner objectives are specified. The most meaningful concept development is likely to result from learning outcomes that address the concept in the most generalizable form possible. The sample objectives that follow are representative of a larger number that are particularly useful in promoting the understanding of and ability to appropriately apply the concept of cycle.

The objectives of this (lesson, unit, course, program) are for you to:	You will know that you are making progress when you can:
1. Increase your understanding of the concept of cycle.	1a. Define cycle in your own words. 1b. Operationally define cycle. 1c. List several examples of cyclic phenomena. 1d. Critique an article/report that purports to have discovered a cyclic phenomenon. 1e.
2. Extend your ability to quantify cycles.	2a. Measure the period and/or frequency of a given cyclic phenomenon. 2b. Calculate the period and frequency of a cyclic phenomenon when given the appropriate data. 2c. Construct a graph illustrating the cyclic nature of a phenomenon. 2d. Predict the next occurrence of a phenomenon from given data that claim to demonstrate its cyclic nature. 2e.
3. Further your ability to identify examples of cycles.	3a. Identify any cycles present in given graphical data. 3b. Select from a list of common phenomena those that exhibit cyclic behavior. 3c. Analyze your observations of a demonstration to determine if any cycles are present. 3d.
4. Expand your ability to identify the sequence of events in a cycle.	4a. Identify the objects/events/conditions that are part of the cycle for a given example of a cyclic phenomenon. 4b. Order given event descriptions in such a manner that they represent a possible cycle. 4c.
5. Extend your knowledge of the way in which cycles can be changed, broken or stopped.	5a. Identify factors that may produce variation in cycles. 5b. Predict the effect on a given cycle of altering a given event or condition in a particular manner. 5c. Recommend a specific step that could be taken to break a given cycle. 5d.
6. Develop an appreciation for the value of the concept of cycle.	6a. Choose to continue to develop your concept of cycle. 6b. Choose to use the concept of cycle to appropriately describe a newly experienced phenomenon. 6c.

Sample Test Questions

The sample evaluation items and their accompanying commentaries are intended to further illustrate the difference between concept-oriented learning outcomes involving the big ideas or major concepts in science and the more familiar content-oriented outcomes.

Question 1:



The period of the cycle illustrated in the graph above is

A. 1 second
B. 2 seconds
C. 3 seconds
D. 4 seconds
E. 9 seconds

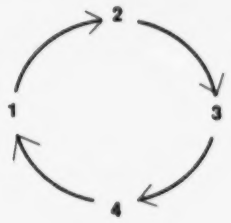
Commentary: This concept-based test item requires the student to know the operational meaning of period and to be able to identify one or more cycles from the graphical presentation. A noncycle specific skill required is the ability to read values from a graph. The appropriateness of this item for concept measurement is dependent upon the graph reading skill being in place. This item could be used to assess Sample Objectives 2 and 3. The correct response is "B."

Question 2: ***Which best demonstrates the concept of cycle?***

A. The first snow of each year
B. Appearance of spring flowers each year
C. Beginning of the falling of leaves each year
D. Appearance of a full moon
E. The onset of the cold and flu season

Commentary: This item requires learners to assess the "degree of fit" of several familiar natural phenomena to the mental construct of cycle. While all of the examples could be considered cyclic phenomena, the most predictable recurring event or condition ("D") is the best choice. This item is appropriate for assessing Sample Objectives 1 and 3.

Question 3: ***The illustration below represents a cyclic phenomenon composed of four sequential events.***



The most probable effect on the cycle of preventing "event 3" from taking place is:

A. No effect
B. Stopping the cycle
C. Slowing the rate at which the events take place
D. Reversing the order in which the events take place
E. Creating a "new" cycle involving only events 1, 2, and 4

Commentary: This item utilizing a generic cycle is well suited to assessing a student's understanding of the concept. In order to respond correctly, the student must operationally grasp the sequential nature of the cycle's events and then analyze the impact of the intervention. This question would be suitable for assessing Sample Objective 5. The correct response is "B."

Question 4: ***Which is not a component of the water cycle?***

A. Precipitation
B. Evaporation
C. Condensation
D. Transpiration
E. Oxidation

Commentary: This item is not suitable for assessing the level of development of the concept of cycle. In order to respond correctly, students must recall specifically the processes typically involved in the water cycle. Little or no understanding of cycle is required in order to achieve success on the item. The correct response is "E."

For Further Information About Cycle

Dewey, E. R. *Cycles*. New York: Hawthorn Books, 1971.

Dewey, E. R. and R. R. Ward. "If You Look Hard, Cycles Are All Over." *Smithsonian*, March 1977. This article is suitable for older student use.

Huff, D. *Cycles In Your Life*. New York: W. W. Norton, 1964. This book is suitable for younger student use.

Exemplary Units

"Cycles" (Grade 10), Division of Instruction, Department of Science, Rochester Public Schools, Rochester, New York, 1977.

ENERGY MATTER

by David C. Cox
Portland State University

Science Concept Working Paper #4 **Fall 1989**

Introduction

"Energy-matter" is perhaps the most potentially fundamental major concept in science, since it is concerned with the "stuff" from which everything is made and the "fuel" that drives our dynamic environment. For most of us, our common experience and, perhaps, formal education have led us to treat matter and energy as separate and distinct entities. The contemporary scientific view is quite different. Energy and matter are now treated as interchangeable expressions of one entity known as "energy-matter."

The Concept

Most of us are operationally dealing with three concepts (i.e., energy, matter, energy-matter) when addressing this idea. Therefore, it seems appropriate to use a three-pronged approach in this section. Of the three concepts, matter is probably perceived to be the most concrete and manageable, followed by energy, and finally energy-matter.

Matter

Somewhat traditionally, we have described that which we classify as matter as anything that has weight and takes up space. While there are a number of properties that can be used to help describe a given sample of matter (e.g., weight, volume, density, temperature, color, shape, texture), the one that appears to be most constant and useful is mass. Mass is defined as the quantity of matter present and is measured by using a balance. The standard unit for mass is the kilogram. Mass should not be confused with weight, which is a measure of the net gravitational force acting on matter.

Matter may exist in the various states identified as solid, liquid, gaseous, or plasma. Regardless of the state, pieces of matter are capable of interacting with each other.

Energy

Energy is a pervasive, but somewhat elusive concept. A concise, meaningful description of energy just doesn't seem to exist. Energy is a fundamental concept but at the same time, extremely diverse and abstract. Literally, wherever you look, the concept of energy is being applied.

In an overly simplistic sense, energy is that which can bring about change (e.g., change in location, change in speed, change in direction, change in temperature, change of state, change in chemical bonding). From a slightly different perspective, energy is that which enables a material system to bring about change in itself and other systems when interacting with them. Glossaries and other sources often describe energy as the ability to do work.

Matter has traditionally been viewed as possessing varying amounts of energy by virtue of its structure (e.g., atoms, molecules, bonding), position, temperature, and degree of motion. The internal energy of the atom is associated with such things as nuclear bonding and the location and interaction of electrons. Molecules are viewed as having additional energy, not only because of the increased numbers of atoms, but also due to the bonding between the atoms. Energy associated with position is often referred to as potential energy (e.g., gravitational potential energy, electric potential energy), while energy associated with movement (e.g., speed) is usually referred to as kinetic energy. The sum of the kinetic energies of the atoms comprising a sample of matter is known as the sample's heat energy or heat content.

Energy appears to be in a nearly constant process of being transferred from one place to another (e.g., sun to earth, stove to cooking utensil, around a home or school) or from one form to another (e.g., electrical to light, electrical to heat, kinetic to potential, kinetic to heat). Energy can be supplied by many different sources and has a wide array of forms, such as chemical, heat, sound, light, electrical, potential, kinetic, and nuclear.

Fortunately, even though there are a huge number of forms of energy, it is measured in one standard unit (or it is measured in a unit easily converted to this standard unit!). The unit for energy is the joule, which is equal to the amount of energy needed to accelerate a 1 kg mass at the rate of 1 m/s/s under frictionless conditions through a distance of one meter. That sounds a little complicated. One hundred joules of electrical energy are needed to keep a 100 watt light bulb operating for 1 second.

Energy-Matter

Energy-Matter is the newest concept of the three we have been discussing. The basic idea of energy-matter is that what we have previously classified as different--matter and energy--are actually two different aspects of the same thing. This "thing" is energy-matter. In other words, energy and matter are interchangeable!

This means that properties previously assigned to either matter or energy are now common properties of energy-matter. For example, any sample of matter has both a mass and an equivalent wavelength. A chunk (i.e., quantum) of energy has both a wavelength and a mass equivalent. Thought of another way, when something gains energy, it also gains mass, since it has gained energy-matter.

Closely related major science concepts include cause-effect, change, cycle, entropy, equilibrium, field, force, fundamental entities, interaction, order, resonance, and system.

Sample Instructional Objectives

From an instructional point of view, a concept takes on operational meaning when learner objectives are specified. The most meaningful concept development is likely to result from learning outcomes that address the concept in the most generalizable form possible. The sample objectives that follow are representative of a larger number that are particularly useful in promoting the understanding of and ability to appropriately apply the concept of energy-matter.

The objectives of this (lesson, unit, course, program) are for you to:	You will know that you are making progress when you can:
1. Further develop your concept of matter.	1a. Operationally define matter. 1b. List at least five measureable attributes of matter. 1c. Name and describe the various states in which matter exists. 1d. Differentiate matter, mass, and weight. 1e.
2. Expand your concept of energy.	2a. Operationally define energy. 2b. List at least five different types/forms of energy. 2c. Differentiate potential, kinetic, and heat energy. 2d.
3. Increase your understanding of the concept of energy-matter.	3a. Operationally define energy-matter. 3b. Critique a given definition of energy-matter. 3c.
4. Value the concept of energy-matter for its predictive and explanatory power.	4a. Choose to further develop your personal concept of energy-matter. 4b. Choose to use the concept of energy-matter when appropriate. 4c.

Sample Test Questions

The sample evaluation items and their accompanying commentaries are intended to further illustrate the difference between concept-oriented learning outcomes involving the big ideas or major concepts in science and the more familiar content-oriented outcomes.

Question 1: ***The quantity of energy-matter present in a given sample is appropriately measured in***

A. kilograms.
B. joules.
C. kilograms/m^3.
D. degrees kelvin.
E. A or B

Commentary: This concept-based item requires the learner to acknowledge the interchangeable aspects of energy and matter in terms of the measurement units for quantity. Two of the distractors offer units for other measurable attributes of energy-matter. The correct response is "E," and the question is suitable for use with Sample Objective 3.

Question 2: ***The idea of energy-matter is fundamentally that "matter can be changed into energy and energy can be changed into matter." This statement***

A. adequately captures the basic idea.
B. would be adequate if the term "converted" were substituted for the word "changed."
C. is misleading since it suggests that matter and energy are two different "things."
D. needs to be amended to emphasize the difficulty of such conversions by adding, "under unusual and difficult to achieve conditions."
E. would be fundamentally correct if it had added, "when nuclear changes are involved."

Commentary: This high level, concept-based question requires the student to selectively critique a given description of the idea of energy-matter. Choosing any one of the distractors is indicative of the misconception that energy and matter are two different "things." The correct response is "C," and the item is suitable for use with Sample Objective 3.

Question 3: ***Which is the calculated wavelength of a 1.0 kg mass moving with a speed of 100 m/s?***

A. 3.0×10^{8}m
B. 5.0×10^{-7}m
C. 6.6×10^{-36}m
D. 9.9×10^{-39}m
E. none of the above

Commentary: Even though it is concerned with the concept of energy-matter, this is NOT an example of a concept-based question. In order to respond correctly, the student must recall a specific equation and numerical constant. In addition, certain mathematical skills are assumed to be in place. It is unlikely that a correct response would be forthcoming without prior study and practice in solving similar types of problems.

Question 4: ***Which analog best conveys the idea of energy-matter?***

A. Water in the solid and gaseous states
B. Hydrogen and oxygen combining chemically to form water
C. Water being decomposed into hydrogen and oxygen
D. A salt water solution
E. A sponge saturated with water

Commentary: This concept-based item requires students to utilize their concept of energy-matter to select the best fitting analog. The correct response is "A," and the item is suitable for use with Sample Objective 3.

For Further Information About Energy-Matter

Reading Material

Karplus, Robert and Lawson, Chester A. *SCIS Teacher's Handbook.* Berkeley, CA: University of California, 1974.

ORGANISM

by David C. Cox
Portland State University

Science Concept Working Paper #5 **Fall 1989**

Introduction

The concept of "organism" is perhaps more closely associated with one particular area of science than any of the other major concepts. In its most basic application, organism is applied to those individual, open and dynamic systems that we characterize as living, be they plants, animals or microorganisms.

Those living things that we categorize as organisms play a critical role in populations, are key components of many cycles, and often serve as fundamental entities. An understanding of and ability to appropriately apply the concept of organism is critical for today's scientifically literate citizen.

The Concept

In the most direct sense, an organism is a complete individual living thing. An organism might be thought of as the "package" or entity that contains all of the necessary components to be classified as a self-contained living thing of its type. Examples of organisms include individual plants, animals, protists (i.e., having both plant and animal characteristics), and microorganisms (i.e., living things too small to be observed directly with the unaided eye). Phenomenal diversity exists among organisms, ranging from single-celled entitites (e.g., paramecium, euglena, amoeba) to multi-cellular examples (e.g., rodents, fish, rose bushes, dandelions, camels, coleus plants, humans, algae, birds, frogs) featuring a variety of collections of tissues, organs, etc.

Regardless of the particular organism in question, it must exhibit those collective characteristics that define "living" things. These characteristics include, but are not limited to, the ability to use materials and energy for growth, maintenance of processes, etc., the capacity to reproduce its kind, and the ability to respond to the environment. Keep in mind that it is often difficult to distinguish living from nonliving things on the basis of a single property.

One of the key attributes of organisms is that they interact with each other as well as with other aspects of their environment. Some of these interactions, from the frame of reference of the organism, are positive (e.g., necessary for survival), while others appear to be negative (e.g., deprive the organism of nutrients, cause death). On the larger scale, however, these interactions are key ingredients of natural cycles and other dynamic systems.

The concept of organism has several applications that expand its usefulness significantly. The concept can be appropriately applied to formerly living things, as well as those individual living things that are alive today. In addition, organism can be used as an analog. Among other things, factories, cities, automobiles, heavy machinery, and even the earth have been described as analogous to an organism.

Closely related major science concepts include cause-effect, change, cycle, energy-matter, entropy, equilibrium, evolution, field, fundamental entities, interaction, invariance, model, order, perception, population, symmetry, and system.

Sample Instructional Objectives

From an instructional point of view, a concept takes on operational meaning when learner objectives are specified. The most meaningful concept development is likely to result from learning outcomes that address the concept in the most generalizable form possible. The sample objectives that follow are representative of a larger number that are particularly useful in promoting the understanding of and ability to appropriately apply the concept of organism.

The objectives of this (lesson, unit, course, program) are for you to:	You will know you are making progress when you can:
1. Increase your understanding of the concept of organism.	1a. Operationally define the concept organism. 1b. List examples of different types of organisms. 1c. Differentiate organism, fundamental entities, and population. 1d. Critique a given description of organism. 1e.
2. Improve your ability to apply the concept of organism.	2a. Identify examples of organisms. 2b. Correctly utilize the concept of organism when describing/explaining a new situation. 2c. Appropriately use organism as an analog. 2d.
3. Value the concept of organism for its explanatory and predictive power.	3a. Elect to use the concept organism when the situation is appropriate. 3b. Choose to continue to develop your personal understanding of organism. 3c. Value explanations and predictions correctly based on the application of the concept organism. 3d.

Sample Test Questions

The sample evaluation items and their accompanying commentaries are intended to further illustrate the difference between concept-oriented learning outcomes involving the big ideas or major concepts in science and the more familiar content-oriented outcomes.

Question 1: ***Organism can appropriately be applied to***

A. a dandelion plant.
B. a dog.
C. a fossil of a prehistoric plant.
D. individual single-celled animals.
E. all of the examples listed above.

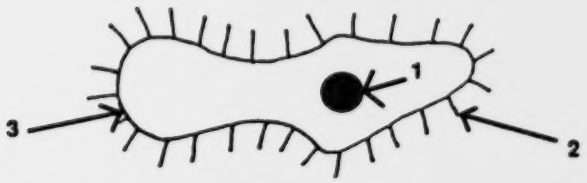
Commentary: This concept-based item is designed to assess the breadth of students' understanding of the concept organism. In addition to understanding the concept's use with living things, students must demonstrate knowledge of its appropriateness for use with things that were once living. The correct response is "E," and the question is suitable for use with Sample Objective 2.

Question 2: ***Organisms are characterized by currently or in the past***

A. being open dynamic systems.
B. having the capacity to reproduce their kind.
C. being able to utilize matter and energy for growth.
D. having the ability to sustain life processes.
E. demonstrating all that are listed above.

Commentary: This concept-based question is intended to assess the learner's knowledge of the attributes necessary for inclusion under the concept organism. The correct response is "E," and the item is appropriate for use with Sample Objective 1.

Question 3: ***The structures identified by the designations 1, 2 and 3 respectively, are:***



A. Mitochondrion, flagellum, cell wall
B. Vacuole, septum, endoplasmic reticulum
C. Ribosome, strobilus, egg sack
D. Nucleus, cilium, cell membrane
E. Chloroplast, pedicel, cytoplasm

Commentary: This is NOT an example of a concept-based question. While the question deals with an example of an organism, it requires the recall of detail rather than an understanding of or ability to apply the concept.

Question 4: ***It has been said that a factory is like a giant organism. Which characteristic of a factory would NOT be consistent with this analogy?***

A. One or more energy sources is required.
B. Waste products are produced.
C. It can be shut down and restarted at any later time.
D. A variety of functions are performed by various portions of the factory.
E. It interacts with its environment.

Commentary: This concept-based item is designed around the use of organism in an analogous situation. In order to respond correctly, the learner must demonstrate an understanding of the attributes of an organism. The correct response is "C," and the question is consistent with the intended learning outcome described in Sample Objective 2.

For Further Information About Organism

POPULATION

by David C. Cox
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Science Concept Working Paper #6 **Fall 1989**

Introduction

When groups or collections of similar "things" are of interest or to be studied formally, the concept "population" is frequently employed. These designated populations, be they composed of people, trees, stars, or atoms, are characterized by a number of descriptive factors (e.g., size, location) that may change through time. In fact, it is often these changes in the population that are of most interest to us, since they assist us in providing explanations and making predictions.

The Concept

In the simplest sense, populations are groups of "things" that are similar in one or more ways. For purposes of designing experiments, gathering data, etc., it is important that the population be specifically identified or described. In general it is necessary, at a minimum, to identify specifically the kinds of things to be included (e.g., dogs, black holes, deciduous trees, homeless people, radioactive elements) and specify the limits in time (e.g., current, year, day) and space (e.g., United States, Alaska, m^3, ml). The following examples identify/describe populations at the minimum level.

The coyote population in Deschutes County in July of 1987.
The red giant population in our galaxy at present.
The giant sequoia population in the Redwood National Park in 1980.
The population of 1956 Ford Thunderbirds still in service.

There are a number of observable/measurable characteristics that can be used to describe populations. Some are generally applicable, such as size (e.g., the number of "things" comprising the population), location, and time frame. Many other characteristics are appropriate for use with certain types of populations. Examples of these would be density, growth rate, radiation emission level, behavior patterns, movement patterns, and distribution. When populations of humans are involved, sex, age, race, ethnic makeup, religion, education, occupation, and income are among characteristics studied.

In some instances, the entire population of interest can be observed directly (e.g., dandelions in a given yard, students in a classroom, geysers in Yellowstone National Park). There are other cases, however, where the size, location, distribution, etc. of the units comprising the population make direct observation impossible. In the case where complete direct observation is not possible, inferences about the population as a whole are made by sampling. This technique consists of selecting certain members of the population (usually randomly selected) and from measurements and/or other observations made on these sample members, inferring the characteristics of the population as a whole. A variety of statistical procedures, laws, equations, etc. have been devised to assist in this process.

While individual populations are often intensely studied, interactions between populations are also frequently of great interest. An example of this would be predator-prey population relationships.

In summary, a collection or aggregate of similar things can be categorized as a population. At a minimum, a population must be defined in terms of its member "units", location, and time frame. Many other characteristics can be used to more completely describe a population. It is important to remember that when studying populations, we are concerned with the population characteristics rather than those of its individual members. When conditions do not allow complete direct observation of the population, sampling techniques are employed so that we can make inferences about the population as a whole.

Sample Instructional Objectives

From an Instructional point of view, a concept takes on operational meaning when learner objectives are specified. The most meaningful concept development is likely to result from learning outcomes that address the concept in the most generalizable form possible. The sample objectives that follow are representative of a larger number that are particularly useful in promoting the understanding of and ability to apply the concept of population.

The objectives of this (lesson, unit, course, program) are for you to:	You will know that you are making progress when you can:
1. Improve your ability to describe/identify populations.	1a. Operationally define a population. 1b. List the essential characteristics required to describe/identify a given population. 1c. Critique a given definition/description of a population. 1d.
2. Extend your knowledge of the characteristics useful in describing populations and changes within populations.	2b. List at least four characteristics appropriate for use in describing a population of inanimate things. 2c.
3. Increase your understanding of the process of making inferences about populations from samples.	3a. Differentiate population, sample, and population unit. 3b. In your own words, describe "random selection." 3c.
4. Extend your ability to quantify populations.	4a. List at least five characteristics of a population that can be quantified. 4b. When given size and time data for a population, appropriately display the data in graphical form. 4c.

Sample Test Questions

The sample evaluation items and their accompanying commentaries are intended to further illustrate the difference between concept-oriented learning outcomes involving the big ideas or major concepts in science and the more familiar content-oriented outcomes.

Question 1: ***Which contains the minimum information required for describing a population?***

A. Mice
B. Grasshoppers in a given field
C. Ants in an anthill in Oregon
D. Automobiles sold in the United States during 1987
E. All of the above

Commentary: This higher level concept-based item requires students to demonstrate their knowledge of the minimum information required to identify a population. In order to knowingly respond correctly, the student must know and comprehend the minimum requirements, and then analyze each choice to see if the minimum requirements are present. The item is appropriate for assessing Sample Objective 1. The correct response is "D."

Question 2: ***Which is an example of a population?***

A. The weeds currently in a given yard
B. The eagles nesting along the Wallowa River in 1984
C. All glaciers in Alaska in 1987
D. All fifteen-year-old students enrolled in United States public schools during 1988
E. All of the above

Commentary: This concept-based item requires students to know, comprehend, and apply their understanding of the attributes associated with a "population." The intended correct choice is "E," and the item is suitable for use in assessing Sample Objective 1.

Question 3: ***Which is closest to the present total population of people in the United States?***

A. 67 million
B. 100 million
C. 220 million
D. 510 million
E. 750 million

Commentary: This is not a concept-based question. In order to knowingly respond correctly (choice "C"), the student must have been exposed to the specific numerical answer and recall/recognize that answer. The act of recalling a number does not in itself indicate the level of development of the concept.

Question 4: ***A student defines population as "a group of individual organisms of the same species." This definition of "population"***

A. represents an acceptable view of the general concept *"population."*
B. is too narrow primarily because it restricts members of a population to *"organisms of the same species."*
C. would be acceptable if *"same species"* were dropped.
D. should be changed to indicate that populations are composed of *"a group of people living in a designated area."*
E. should have substituted *"plants or animals"* for *"organism."*

Commentary: This higher level concept-based item is suitable for use in assessing Sample Objective 1. The item requires students to evaluate the responses on the basis of their level of understanding of the general concept of population. The intended correct response is "B."

For Further Information About Populations

Showalter, Victor, et al. (ed.). *Unified Science Premises and Prospects.* Columbus, OH: Federation for Unified Science Education, 1975.

Activities

Dyche, Steven E. "Population Activities for Middle School Science." *Science Scope* 9(Nov. 1985):26-27.

FORCE

by David C. Cox
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Science Concept Working Paper #7 **Fall 1989**

Introduction

"Force" is a critical concept in science's storehouse of explanatory power. The use of the concept represents our primary way of explaining starting, stopping, changing direction, floating, falling, and a host of other movement-related phenomena. Interestingly enough, we also use the force concept in explaining a lack of movement.

Force is a powerful idea in helping us to better understand and interact with our environment. We use the idea in a diverse number of ways, ranging from the forces acting between and within the fundamental building blocks of matter to those that formed some mountain ranges and keep our solar system "together," as well as those that convince us to make the choice to buckle up our seat belts. Truly, force does "make it happen."

The Concept

In its simplest form, a force is a push or a pull. Forces can be contact (e.g., one car pushing another, someone pulling a wagon) or noncontact (e.g., acting at a distance as in gravitational force).

Forces have both a magnitude (size) and direction. The direct measurement of magnitude is accomplished by the use of a spring scale, where the force of interest either compresses or stretches a spring that has been calibrated in force units. In the International System of Units (SI), force is measured in newtons, while in the English system force magnitudes are expressed in pounds.

The direction of a force can be described in a variety of ways. The simplest approach is "up, down, forward, or backward." Perhaps a little more sophisticated approach would be to use geographic nomenclature such as "north, south, east, or west" or degrees variation from these directions. A complete description of a force requires both a magnitude and direction.

Forces can be represented by the use of directed line segments, more commonly thought of as arrows, and technically termed, force vectors. The arrowhead indicates the direction that the force acts, and the length of the arrow is used to indicate the magnitude of the force. Forces can be added, subtracted, and have other mathematical operations performed by application of a form of mathematics known as vector algebra.

If a force is partially or totally unbalanced (nothing offsetting it), it will produce a change in the state of motion (e.g., speed up, slow down, change the direction of) the object(s) it acts on. On the other hand, when two or more forces acting on a single object offset (balance) each other, the net force is zero, and the object is said to be in force equilibrium. The object will retain the state of motion it possessed at the moment force equilibrium was established.

Among the common examples of important contact forces are friction, buoyancy, lift, and those exerted by wind, water, steam, burning gases, and springs. The most often encountered forces acting at a distance are gravitational, electrical and magnetic.

While there is some disagreement over the appropriateness of such a use, the force idea is used and useful outside the physical force range. We are all familiar with uses such as peer pressure, public opinion, political pressure and forced hand being used to explain what caused people to take or not take certain actions. Operationally, these psychological forces are pushes and pulls influencing people's decisions, behavior and emotions.

In summary, forces are pushes or pulls. They can be exerted by objects in contact or act at a distance. Forces have both magnitude and direction and can be added together to determine the net force acting on an object. Unbalanced forces produce a change in the state of motion of the objects they act on, while balanced forces do not alter the motion of objects on which they act.

Sample Instructional Objectives

From an instructional point of view, a concept takes on operational meaning when learner objectives are specified. The most meaningful concept development is likely to result from learning outcomes that address the concept in the most generalizable form possible. The sample objectives that follow are representative of a larger number that are particularly useful in promoting the understanding of and ability to appropriately apply the concept of force.

The objectives of this (lesson, unit, course, program) are for you to:	You will know that you are making progress when you can:
1. Increase your understanding of the concept of force.	1a. Operationally define force. 1b. Demonstrate at least three different types of forces. 1c. Critique another student's description of force. 1d.
2. Develop your skill at using instruments for measuring forces.	2a. Use a spring scale to weigh a given object. 2b. Use a spring scale to measure the frictional force acting on an object. 2c. Use a compass to measure the direction of a force. 2d.
3. Extend your knowledge of the relationship between force and motion.	3a. Demonstrate a situation where force causes a motion. 3b. Predict the effect of a given force acting on a given object. 3c. Demonstrate a situation where a force causes motion to cease. 3d.
4. Increase your understanding of the ways in which forces can be changed.	4a. Demonstrate how pulleys can be used to change the direction of a force. 4b. Demonstrate how pulleys can be used to change the amount of force needed to lift an object. 4c.
5. Extend your awareness of the forces in your environment.	5a. Correctly match the names of forces with illustrations depicting each. 5b. List at least five examples of forces in your environment. 5c. List at least three forces that directly affect you everyday. 5d.

6. Improve your ability to use the idea of force.

6a. Use the idea of force to appropriately explain a newly experienced phenomenon.

6b.

7. Extend your skill in using numbers, relationships, and graphs when using the concept of force.

7a. Interpret a given distance vs. time, speed vs. time, or acceleration vs. time graph in terms of the force acting on the object whose motion is graphed.

7b. Appropriately apply Newton's three laws of motion when explaining motion or lack of motion in terms of force.

Sample Test Questions

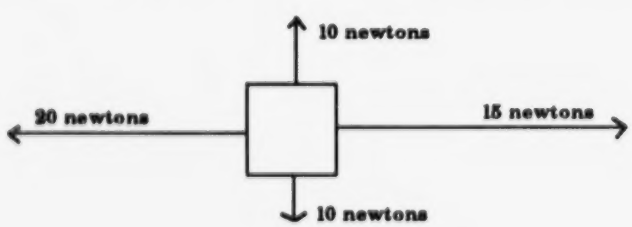
The sample evaluation items and their accompanying commentaries are intended to further illustrate the difference between concept-oriented learning outcomes involving the big ideas or major concepts in science and the more familiar content-oriented outcomes, even though the differences are perhaps less pronounced than usual when examining the concept of force.

Question 1: ***An object is at rest on a level table. In order to explain why it is at rest, the minimum number of forces needed, in addition to gravity, will be***

A. 0 forces
B. 1 force
C. 2 forces
D. 3 forces
E. 4 forces

Commentary: This item is suitable for assessing a student's development of the concept of force. In order to knowingly respond correctly, the student needs to know that rest can be explained by the use of the force idea, and that for such a case, the net force acting must be zero. Since gravity acts down on the object, at least one additional force must be balancing that exerted by gravity. This item would be appropriate for use with sample Objective 6. The correct response is "B."

Question 2: ***All of the forces acting on an object initially at rest are identified in the sketch.***

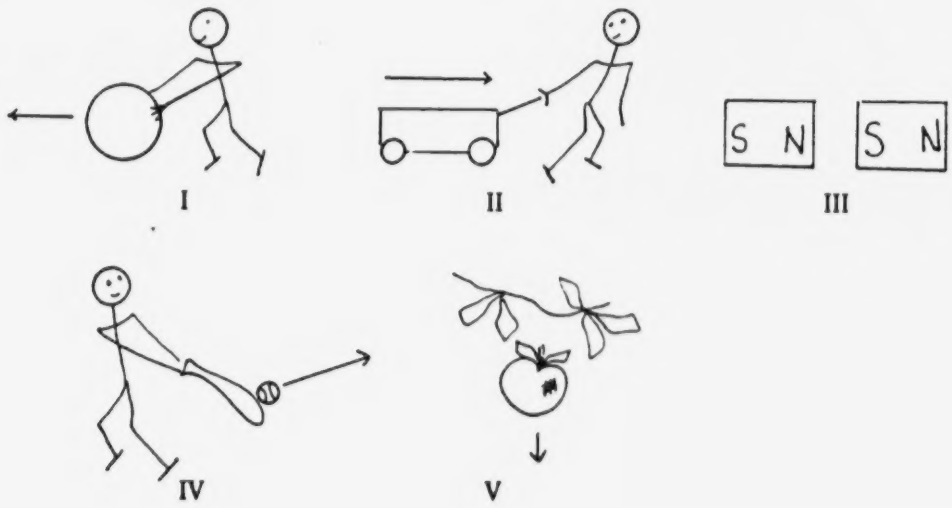


After the forces act on the object, the object will most likely be

A. at rest.
B. moving up.
C. moving up and to the right.
D. moving to the left.
E. moving down and to the left.

Commentary: This concept-based item requires students to demonstrate their understanding of balanced and unbalanced forces and their connection to motion. This item is suitable for assessing sample Objective 3. The correct response is "D."

Question 3:



Which illustrations show one or more forces acting on an object?

A. I & II
B. III & V
C. I, II, & IV
D. I, II, III, & IV
E. I, II, III, IV, & V

Commentary: This concept-based test item requires students to recognize examples of situations where both contact and noncontact forces are connected to motion. The intended correct response is "E," and the item is suitable for assessing sample Objective 3.

Question 4: ***Forces can be responsible for which of the following?***

A. Starting motion
B. Stopping motion
C. Changing the direction of motion
D. Keeping an object from moving
E. Any of the above

Commentary: This item is closely related to sample Question 3 and is suitable for assessing the level of development of the concept force. In order to knowingly respond correctly and select choice "E," the student must be aware of the rich variety of connections between force and motion. This item is appropriate for evaluating progress towards achieving sample Objective 3.

Question 5: ***How far will a 1 kg object near the surface of the earth fall in 0.01 s when the only force acting on it is that due to gravity?***

A. 0.0005 m
B. 0.0490 m
C. 0.0980 m
D. 1.0000 m
E. An object will not move any distance in such a short period of time due to its inertia.

Commentary: This content-based item is inappropriate for assessing the level of development of the concept force. The ability to select the correct choice requires the recall of several pieces of specific information (e.g., acceleration due to gravity, formula for calculating distance) but no direct application of the concept force.

For Further Information About Force

American Association for the Advancement of Science. *Commentary for Teachers.* Any Edition.

INTERACTION

by David C. Cox
Portland State University

Science Concept Working Paper #8 **Fall 1989**

Introduction

The concept of "interaction" may be the giant umbrella under which most, if not all, of the major science concepts fall. This idea transcends all of the science disciplines, as well as being widely used in the other human ways of knowing and many everyday situations.

This cornerstone idea of mutual influence lies at the heart of cause-effect relationships, cyclic phenomena, and systems, to mention just a few examples. To grasp the meaning of, and to develop the ability to appropriately apply this concept, is of genuine fundamental importance.

The Concept

In a nutshell, interaction is reciprocal or mutual action or influence between two or more objects or things. As this brief description implies, the concept is extremely useful across all science disciplines and is also widely applicable outside the realm of science.

The mutual action or influence between two or more things can occur between inanimate objects, between living things, and/or between the animate and inanimate. Examples of such diverse interactions include collisions between billiard balls, symbiosis (i.e., two dissimilar organisms living in close association or union advantageous to both), and the many exchanges and other interactions between a tree system and its inanimate environment (e.g., soil, atmosphere).

Interaction can take place between things in direct physical contact, those that are separated in space, and/or those in a combination of these two conditions. Examples would include such phenomena as bank erosion created by a river or ocean waves, a satellite orbiting the earth, and the gaseous atoms and molecules in the atmosphere.

Many interactions are able to be observed directly (e.g., magnetic attraction and repulsion, fertilization of an egg, earthquake waves), while others are hypothesized as components of a variety of models and theories (e.g., plate tectonics, atomic model, kinetic-molecular theory, Mendelian genetics). Both categories are extremely useful for explanatory and predictive purposes.

Interactions occur both naturally (e.g., pollination, chemical reactions, lightning) and due to the planned activity of humans. Some of these human-created interaction situations are designed primarily to influence, such as television commercials, music and lyrics, and speeches. Other instances are targeted to cause a certain action, such as death of rats due to planted poison, a thermostat turning on or off the heating/cooling system, and a political campaign to generate votes.

Our primary basis for identifying phenomena involving interaction is the observation of change. The identification of change serves as evidence of interaction either having taken place or occuring at the time of the observation.

Closely related major science concepts include cause-effect, change, cycle, energy-matter, entropy, equilibrium, evolution, field, force, fundamental entitites, gradient, model, order, organism, perception, population, resonance, symmetry, system, theory, and time-space.

Sample Instructional Objectives

From an instructional point of view, a concept takes on operational meaning when learner objectives are specified. The most meaningful concept development is likely to result from learning outcomes that address the concept in the most generalizable form possible. The sample objectives that follow are representative of a larger number that are particularly useful in promoting the understanding of and ability to appropriately apply the concept of interaction.

The objectives of this (lesson, unit, course, program) are for you to:	You will know that you are making progress when you can:
1. Increase your understanding of the concept of interaction.	1a. Operationally define interaction. 1b. List examples of interaction. 1c. Differentiate interaction, cause-effect, change, and cycle. 1d. Critique a given definition of interaction. 1e.
2. Improve your ability to use the concept of interaction.	2a. Operationally define "evidence of interaction." 2b. Identify situations where the use of interaction is appropriate. 2c. Appropriately apply the concept of interaction when explaining a newly experienced phenomenon. 2d. Critique another person's use of the concept of interaction in explaining a phenomenon. 2e.
3. Value the concept of interaction for its explanatory and predictive power.	3a. Choose to further develop your concept of interaction. 3b. Value explanations and predictions based upon the appropriate use of interaction. 3c. Choose to use interaction when explaining phenomena and/or making predictions.

Sample Test Questions

The sample evaluation items and their accompanying commentaries are intended to further illustrate the difference between concept-oriented learning outcomes involving the big ideas or major concepts in science and the more familiar content-oriented outcomes.

Question 1: ***Which is an example of interaction?***

A. A magnet attracting a nail
B. A person breathing
C. A fish swimming
D. A satellite orbiting the earth
E. All of the above

Commentary: This concept-based question is concerned with the student's understanding of the range of phenomena that represent examples of interaction. Choices include contact interaction, interaction at a distance, interaction between inanimate objects, and interaction between organisms and their environment. The correct response is "E," and the item is suitable for use with Sample Objective 1 or 2.

Question 2: ***Which serve(s) as evidence of interaction?***

A. Increase in temperature
B. Decrease in volume
C. No observable change
D. Constant mass
E. A and B

Commentary: This concept-based item focuses on evidence of interaction. Since observable change serves as our primary evidence, the correct response is "E." This item is suitable for use with Sample Objective 2.

Question 3: ***A student described interaction as, "reciprocal action or influence between two or more things." This description***

A. is o.k. as written.
B. should make it clear that one of the objects acts on another object.
C. should specify that interaction takes place only between things that are in physical contact.
D. would be clarified by indicating that interaction takes place between inanimate things.
E. is not appropriate; this is a description of a system rather than interaction.

Commentary: This higher-level concept-based question requires students to evaluate a description of interaction. All but one of the distractors feature incorrect restrictions (e.g., one-way action only, physical contact required, only between inanimate objects) on interaction. The other distractor indicates that the description is totally inappropriate. The correct response is "A," and the item is appropriate for use with Sample Objective 1.

Question 4: ***Which interaction is credited as being directly responsible for the great San Francisco earthquake of 1906?***

A. Pacific Plate colliding with the North American Plate
B. Right lateral strike-slip
C. Volcanic eruptions
D. Constant creeping
E. Severe erosion

Commentary: This is NOT an example of a concept-based question. Even though interaction is a key component of the question, only recall of specific information will lead to a knowingly correct response. A correct response provides little or no insight into the level of development of the student's concept of interaction.

For Further Information About Interaction

ORDER

by David C. Cox
Portland State University

Science Concept Working Paper #9 **Fall 1989**

Introduction

While arguments may roar as to whether order is present in nature and detected by humans or imposed on nature by creative Homo sapiens, the concept of "order" is omnipresent and powerful. Order implies classes, sequences, patterns, and consistent predictability. As such, the concept is one of the broadest in its range of applicability. It encompasses observable phenomena (e.g., physical patterns, cyclic phenomena) as well as an underlying belief (e.g., the orderly universe). We seek to better understand our world by searching for "order," and many of our more famous have had the knack of "discovering" order where others saw nothing.

The Concept

Order is so broad a concept, that to attempt to discuss it in a singular straightforward sense would be a disservice. Order may take the form of classes, where our classification process creates (discovers?) groups, such as living and non-living, acids and bases, and floating and sinking. Membership in these various classes provides the basis for much in the way of explanation and perhaps more importantly, predictability.

Another form of order is the regular sequence and/or serial ordering. This can take the definite human creation pattern, such as alphabetical order, numerical order, or order by rank (as in the military). These orderings can also be done by virtue of any one or combination of a number of characteristics, such as mass, weight, length, density, wavelength, age, area, or volume.

Order may be identified in patterns in the form of geometric arrangements in space (e.g., crystals, flowers, spider webs). It can also be displayed in repeated events or sequences in time (e.g., phases of the moon, various life cycles, tides).

The belief in the existence of an orderly universe is an article of faith for scientists. It is this belief in the existence of natural rules, fixed relationships, etc. that promises the power of predictability once we have found/created/invented them.

Other major science concepts closely related to order include cause-effect, cycle, entropy, evolution, gradient, perception, probability, and symmetry.

In summary, the concept of order encompasses classes or groups, a wide variety of sequences, and that which we perceive as patterns. In addition, it includes the basic belief in a systematic, predictable universe.

Sample Instructional Objectives

From an instructional point of view, a concept takes an operational meaning when learner objectives are specified. The most meaningful concept development is likely to result from learning outcomes that address the concept in the most generalizable form possible. The sample objectives that follow are representative of a larger number that are particularly useful in promoting the understanding of and ability to appropriately apply the concept of order.

The objectives of this (lesson, unit, course, program) are for you to:	You will know that you are making progress when you can:
1. Increase your understanding of the concept order.	1a. Operationally define order. 1b. Critique a given definition of order. 1c.

2. Improve your ability to recognize order.	2a. Identify examples of order in your environment. 2b.
3. Use order as a basis for making predictions.	3a. Interpolate new data from existing orderly data. 3b. Extrapolate new data from existing orderly data. 3c.
4. Extend your ability to create order from unorganized data.	4a. Organize given data to reveal order. 4b.

Sample Test Questions

The sample evaluation items and their accompanying commentaries are intended to further illustrate the difference between concept-oriented learning outcomes involving the big ideas or major concepts in science and the more familiar content-oriented outcomes.

Question 1:

Which belongs in the blank space?

A.

B.

C.

D.

E. none of the above

Commentary: This concept-based item requires students to identify the characteristic being used for ordering and then identify a missing element in the sequence. This item, for which the correct response is "C," is suitable for use in assessing Sample Objective 3.

Question 2: ***A student's test response defined order as, "an observable pattern." This definition***

A. seems to adequately capture the idea of order.
B. would be improved by omitting "observable."
C. needs to be expanded to include classifying into groups.
D. seems to have confused order with symmetry.
E. needs to be expanded to include the belief in an orderly universe.

Commentary: This higher level concept-based question requires students to evaluate a definition on the basis of their level of understanding of the concept order. The intended correct response is "E." The item is suitable for use in assessing Sample Objective 1.

Question 3:

I

II

III

IV

Which represents order in the form of a sequence?

A. I, II, III, IV
B. I, IV, II, III
C. II, III, IV, I
D. III, IV, II, I
E. IV, III, II, I

Commentary: This concept-based item requires a rearrangement of data to create an orderly arrangement, in this case a sequence. The item is appropriate for use in assessing Sample Objective 4, and the correct response is "D."

Question 4: ***Which is a geometric progression or series?***

A. 1, 2, 3, 6
B. 144, 12, 1, 1/2
C. 1, 4, 7, 10
D. 6, 1, -4, -9
E. 2, 4, 16, 256

Commentary: This is NOT an example of a concept-based question, since to knowingly respond correctly the student must have been previously exposed to both the name and defining "rule" for geometric progressions.

For Further Information About Order

Kemeny, John G., *A Philosopher Looks at Science*. Princeton, NJ: D. Van Nostrand Company, Inc., 1959.

Exemplary Units

"Patterns" (Secondary Level), Science Department, Educational Research Council of America, Cleveland, Ohio

QUANTIFICATION

by David C. Cox
Portland State University

Science Concept Working Paper #10 **Fall 1989**

Introduction

The concept of "quantification" represents a critical idea in science and a valuable asset in everyday decision making. When observations (data!) are quantified (expressed in numbers or measurements), preciseness of communication is enhanced and the opportunity to interpret the data expanded. Therefore, the understanding of and ability to apply the concept of quantification is an important attribute of a scientifically literate citizen.

The Concept

In the most straightforward sense, quantification is the assignment of numbers or measurements to phenomena or observations. There is a wide range of application for this concept. Probably on one end of the application continuum is the formation of groups or classes and the subsequent arbitrary assignment of a numerical designation to each group. Examples of this type of use would be represented by experimental group 3, chimp family number 2, and type 6 mountains.

Another general application of the concept is represented by counting the number of observations or phenomena. This use is exemplified by population sizes, sizes of samples used, or events observed (e.g., days with measurable rain, cell divisions, volcanic eruptions, radioactive disintegrations).

One of the most frequent uses of the concept is the quantifying of observations by the measurement of certain properties, such as length, mass, temperature, quantity of electric charge, intensity, density, electrical conductivity, pressure, speed, and volume. In some cases, the quantification consists of measuring the duration of an observation or phenomenon (e.g., length of an earthquake, time required for an object to travel a certain distance), while in other cases it is the time interval between observations or events (e.g., period of Halley's Comet, the population was determined every 6 months).

Numerical scales are often used to assist us in ordering observations, phenomena, properties, etc. Examples of such scales are the decibel scale for noise level, pH scale for acidity, Richter scale for earthquake magnitude, and IQ for intelligence. Some of these scales are equal interval, while others, due to the nature of what they express, are exponential.

Quantification can take many additional forms including expression as ratio, percentage, proportion, or calculated index (e.g., index of refraction, biological diversity index).

There are several advantages to be realized by applying the concept of quantification. Among these advantages is an increased precision in making observations. Quantifying observations assists us in recording and reporting a "public description" such as measured length rather than a "personal description" such as "small." In addition, communication is enhanced when data are quantified. The language of numbers is perhaps the closest thing that we have to a global language. Also, the quantification of observations and phenomena expands the opportunity for data interpretation, since the power of mathematics and statistics can be added to the interpretation process. Finally, the ability to generate predictions is enhanced by quantification, since many mathematical procedures (e.g., interpolation, extrapolation) can be utilized.

Closely related major science concepts include change, cycle, energy-matter, equilibrium, force, gradient, invariance, order, perception, probability, population, scale, and significance.

Sample Instructional Objectives

From an instructional point of view, a concept takes on operational meaning when learner objectives are specified. The most meaningful concept development is likely to result from learning outcomes that address the concept in the most generalizable form possible. The sample objectives that follow are representative of a larger number that are particularly useful in promoting the understanding of and ability to appropriately apply the concept of quantification.

The objectives of this (lesson, unit, course, program) are for you to:	You will know that you are making progress when you can:
1. Increase your understanding of the concept quantification.	1a. Operationally define quantification. 1b. Identify examples of several different forms of quantification. 1c. Critique a description of the concept quantification. 1d.
2. Extend your knowledge of the advantages to be realized by applying the concept quantification.	2a. List at least four potential advantages gained by applying quantification to observations. 2b. Identify some of the limitations present in a given set of qualitative observations. 2c.
3. Improve your ability to apply the concept of quantification.	3a. Demonstrate your ability to make quantitative observations in a variety of situations. 3b. When given a list of possibilities, identify those observations that have been quantified. 3c.
4. Value the concept of quantification for its explanatory and predictive power.	4a. Choose to quantify observations. 4b. Demonstrate a preference for quantitative data. 4c. Demonstrate a preference for predictions based upon quantitative data. 4d.

Sample Test Questions

The sample evaluation items and their accompanying commentaries are intended to illustrate the difference between concept-oriented learning outcomes involving the big ideas or major concepts in science and the more familiar content-oriented outcomes.

Question 1: ***Which is an example of the use of quantification?***

A. The leaves were bright green and the berries a florescent red.
B. A high percentage of the eggs hatched.
C. Group A had more weight gain than group B.
D. There are twelve glaciers in the park boundaries.
E. All of the above are examples of the use of quantification.

Commentary: This concept-based item requires learners to select the statement that contains direct evidence of the use of quantification. While one choice, "A," is clearly qualitative, two of the other distractors use terms (e.g., percentage, weight gain) that imply the application of quantification. The correct response is "D," and the item is suitable for use with Sample Objective 3.

Question 2: ***The use of quantification***

A. provides more precise descriptions/observations.
B. assists in the clarity of the communication of observations.
C. can be useful when the data are to be interpreted.
D. can facilitate making predictions based upon data.
E. All of the above

Commentary: This item is seeking information regarding the student's perception of the potential advantages to be realized from the application of the concept of quantification. The correct response to this concept-based item is "E," and the question is appropriate for use with Sample Objective 2.

Question 3: ***Which is NOT an example of quantification?***

A. The work is 10 cm long.
B. The liquid boiled at 87° C.
C. The mass of Sample A is three times that of Sample B.
D. Experimental groups 3, 7 and 10 had no measurable changes.
E. Experimental Group C showed a large change in weight over the period of the investigation.

Commentary: This concept-based item requires the student to identify the single statement that does not utilize quantification. Several different applications of quantification (e.g., length measurement, temperature measurement, ratio, group designations) are included in the distractors. The correct response is "E," and the item is appropriate for use with Sample Objectives 1 or 3.

Question 4: ***What is the mean of the five measurements?***

3.10 cm, 3.26 cm, 3.25 cm, 3.25 cm, 3.33 cm

A. 3.23 cm
B. 3.24 cm
C. 3.25 cm
D. 3.26 cm
E. 3.33 cm

Commentary: Even though this item is concerned with numbers, it is NOT an example of a concept-based question for quantification. In order to respond correctly, a student must recall and properly execute the procedure for calculating the arithmetic mean. In addition, skill in rounding is required. A correct response provides little, if any, insight into the student's understanding of or ability to apply the concept of quantification.

For Further Information About Quantification

SYSTEM

by David C. Cox
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Science Concept Working Paper #11 **Fall 1989**

Introduction

Probably no major science concept has its name used as frequently as "system." The list of common uses covers the full realm of science and everyday affairs, and is represented by such diverse examples as the nervous system, solar system, ecosystems, weather systems, chemical systems, highway systems, and weight loss systems. In addition, we hear about people who work as systems analysts or are in the process of utilizing a systems approach.

With the widespread use of the concept, it is imperative that everyone develop an understanding of and ability to appropriately apply the concept. Its explanatory and predictive powers make it a central idea for functioning in today's world.

The Concept

A system consists of a group or collection of interacting or interconnected "things" and is the largest collection of objects taken under consideration for purposes of describing, explaining and/or predicting. In other words, a system is a collection of related "objects" that collectively represent a whole. Because of the necessary interaction or connection between the objects comprising a system, each element or component plays a role in the overall functioning of the system.

The components of a system can be physically separated, such as the members of our solar system, or in contact all or part of the time, as is the case with gear systems and pulley systems. In other cases, the observer can mentally create the components of a system, even when a single object is involved. An example of the latter would be imagining a sheet of paper to be composed of two halves or four quarters.

Subsystems are groups of interacting or interconnected objects within a larger system. For example, the earth-moon system is a subsystem of our solar system, which is in turn a subsystem of our galaxy. It is possible for a given object within a system to be a component of several subsystems.

Systems are often categorized as either "open" or "closed." The closed condition, which may or may not actually be able to be achieved, can range from closed for some specified condition (e.g., mass, force) to completely closed. When not specified, closed generally refers to closed for matter-energy exchange with any other system. Therefore, it is reasonable to think of a closed system as being defined by the matter-energy present when it is identified. In other words, whatever a system is identified as being closed for can neither enter nor leave the system. If such an exchange does happen to occur, the system becomes a new and different system.

Open systems exchange matter-energy with other systems. Therefore, open systems are defined by a bounded region of space rather than by the matter-energy present. The space above the water in a jar partially filled with water is an example. Of course, the most personal example of a dynamic open system is a human being.

The components or elements comprising a system can be inanimate, animate, or a combination of the two. A classic example of the latter category is an ecosystem.

Major science concepts closely related to system include cause-effect, change, cycle, energy-matter, entropy, equilibrium, field, fundamental entities, interaction, organism, population, and resonance.

Sample Instructional Objectives

From an instructional point of view, a concept takes on operational meaning when learner objectives are specified. The most meaningful concept development is likely to result from learning outcomes that address the concept in the most generalizable form possible. The sample objectives that follow are representative of a larger number that are particularly useful in promoting the understanding of and ability to appropriately apply the concept of system.

The objectives of this (lesson, unit, course, program) are for you to:	You will know that you are making progress when you can:
1. Increase your understanding of the concept system.	1a. Operationally define system. 1b. Differentiate system, subsystem, and population. 1c. Differentiate open and closed systems. 1d.
2. Improve your ability to identify systems.	2a. List several examples of natural systems. 2b. List several examples of human-created systems. 2c. When given an object, identify/describe at least one system. 2d.
3. Value the concept system for its explanatory and predictive power.	3a. Demonstrate a preference for explanations and predictions made from the appropriate application of the concept system. 3b. Choose to use the concept system, when appropriate, for making explanations and/or predictions. 3c. Choose to continue your personal development of the concept system. 3d.
4. Extend your ability to appropriately use the concept system.	4a. When asked to explain a phenomenon, identify a potentially useful system and subsystems. 4b. When asked to make predictions regarding a phenomenon, identify a potentially useful system and subsystems. 4c.

Sample Test Questions

The sample evaluation items and their accompanying commentaries are intended to illustrate the difference between concept-oriented learning outcomes involving the big ideas or major concepts in science and the more familiar content-oriented outcomes.

Question 1: ***A closed system***

A. is the only type found in nature.
B. is defined by the matter-energy in it.
C. is composed of inanimate objects only.
D. can exchange matter-energy with nearby systems.
E. does not contain any subsystems.

Commentary: This concept-based item assesses the learner's understanding of "closed system." The key to responding correctly is indentifying which alternative statement describes an attribute of a closed system. The correct response is "B," and the item is suitable for use with Sample Objective 1.

Question 2: ***Which is a subsystem of a house?***

A. The city in which the house is located
B. The family automobile
C. The electrical wiring in the house
D. Street lights visible from the house
E. All of the above are subsystems of a house

Commentary: This item is designed to determine the student's ability to appropriately apply the idea of subsystem. The attributes "within a larger system" (in this case designated as house) and "group of interacting or interconnected elements" must both fit the best choice. This item is appropriate for use with Sample Objective 1. The correct response is "C."

Question 3: ***How much work is required to raise an 80.0 kg mass 5.0 m with a pulley system whose efficiency is 80%?***

A. 5.0 J
B. 80.0 J
C. 4.0×10^2 J
D. 3.9×10^3 J
E. 4.7×10^3 J

Commentary: Even though this item utilizes a "pulley system," it is not a concept-based question. By responding correctly, the student provides no evidence from which to make an inference regarding an understanding of or ability to apply the concept system. A correct response would indicate the ability to recall the procedure for calculating the work done in lifting a mass and an understanding of efficiency. In addition, there would be some demonstrated competence in computational skills.

Question 4: ***Systems***

A. must be closed in order to be useful in explaining phenomena.
B. are natural phenomena as opposed to human-created phenomena.
C. must contain at least one subsystem.
D. are collections of interconnected things.
E. B and C

Commentary: This concept-based item requires students to select the statement most descriptive of or consistent with the concept of system. The desired response is "D," and the question is suitable for use with Sample Objective 1 or 2.

For Further Information About System

For Information and Activities

Thier, Herbert D., et al. *Interaction and Systems SCIIS Teacher's Guide.* Chicago: Rand McNally & Company, 1978.

Thier, Herbert D., et al. *Subsystems and Variables SCIIS Teacher's Guide.* Chicago: Rand McNally & Company, 1978.

EQUILIBRIUM

by David C. Cox
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Science Concept Working Paper #12 **Fall 1989**

Introduction

The concept of "equilibrium" is deceptively pervasive both inside and outside the realm of science. This evasiveness is perhaps largely the result of very narrow and isolated views being taken of the meaning and application of the concept during instruction within the various science disciplines. This situation is especially unfortunate in the case of equilibrium, since the opportunity exists for many everyday applications of the concept. A more fully developed concept of equilibrium may even bring enhanced meaning to one of education's most common clichs--the more things change, the more they remain the same!

The Concept

The idea of equilibrium is closely related to that of balance, but the concept of equilibrium is much richer than balance in meaning. Most of us are aware of some of the "classic" examples of the use of the concept. Among these venerable examples are the "static" equilibrium of the balanced teeter-totter, the "dynamic" equilibrium of the reversible chemical reaction, the marvelous physiological stability (homeostasis) of the human body's systems, and the use of the balance between light and heavy rocks in the earth's crust (isostasy) in explaining some of the earth's landforms. Perhaps these examples pinpoint another reason for our limited ability to generalize the concept; we seem to be using the same idea with a lot of different names, each one being somewhat specific to a discipline.

The key to our further development of the concept, however, probably depends upon a better understanding of what these diverse applications have in common, and in fact, what they have in common with some less widely acknowledged and, in some cases perhaps, controversial examples. Falling into this latter category would be such applications as balance of trade, cash flow, balanced budgets, and explanations involving such phenomena as learning, stress management and human behavior.

When we stretch our understanding a bit, we realize that when something (usually a system) is in a state of equilibrium, a balance exists between opposing forces or opposing tendencies. This is a key idea in being able to recognize an appropriate application of the equilibrium concept. The system is characterized by certain properties (e.g., temperature) that remain constant. When labor-management negotiations are underway, for example, an acceptable balance of conflicting interests or desires is being sought. Reaching an equilibrium position, albeit perhaps short-lived, often results in a settlement.

Two major "categories" of equilibrium, the so-called static and dynamic, are rather easily differentiated. Examples of static equilibrium that we should be able to easily relate to are when we manage to balance ourselves on one leg (balancing the forces acting on various parts of the body) and when we design a building that will survive under the stresses of its own weight.

The sometimes dynamic nature of the equilibrium condition is clearly illustrated in chemistry, when the equilibrium state is reached in a reversible chemical reaction. The products of one reaction (e.g., H_2 and 0_2) are utilized as the reactants for the opposite chemical reaction. When the reaction rates in opposite directions are equal, the system is characterized by constant properties and has reached equilibrium.

$$2\,H_2 + 0_2 \rightleftharpoons 2\,H_20_2$$

The "movement" of a system towards or away from an equilibrium state is also of interest. The changes within the system can either be spontaneous or initiated/sustained by external influences.

Some less frequently encountered examples of equilibrium are useful in developing the concept. Some psychologists, for example, explain learning as the process by which humans regain cognitive equilibrium when it has been upset (e.g., by an observed anomaly or discrepant event). Coping with stress might be viewed as an effort to regain the physiological and psychological equilibrium that characterize a person's comfort zone. Some political scientists view stable governments as representing an equilibrium state (no pun intended) between the opposing political forces of the right and left.

When developing the equilibrium concept, four other big ideas or major concepts of science become critical compan-

ions. These are the concepts of system, force, interaction, and energy-matter. Equilibrium conditions exist in the context of systems and interactions within and between systems involving both forces and matter-energy exchange.

In summary, equilibrium is a state of balance or equality in a system existing between opposing forces, tendencies or conditions. A system in equilibrium is characterized by key or indicator properties that remain constant. Two major categories are static (e.g., rest) and dynamic (e.g., active), where the overall balance is sustained despite changes in opposite directions.

Sample Instructional Objectives

From an instructional point of view, a concept takes on operational meaning when learner objectives are specified. The most meaningful concept development is likely to result from learning outcomes that address the concept in the most generalizable form possible. The sample objectives that follow are representative of a larger number that are particularly useful in promoting the understanding of and ability to appropriately apply the concept of equilibrium.

The objectives of this (lesson, unit, course, program) are for you to:	You will know that you are making progress when you can:
1. Increase your understanding of the concept of equilibrium.	1a. Operationally define equilibrium 1b. Distinguish between systems that are and are not at equilibrium. 1c. Identify at least two questions to ask to assist in identifying equilibrium situations. 1d.
2. Further your ability to identify examples of equilibrium.	2a. List at least three examples of dynamic equilibrium in your environment. 2b. List at least three examples of static equilibrium in your environment. 2c.
3. Extend your knowledge of ways to alter or achieve an equilibrium condition.	3a. Identify for a given equilibrium situation variables that could be altered in order to upset the equilibrium. 3b. Identify for a given nonequilibrium situation variables that could be changed in order to bring about equilibrium. 3c. Predict the effect of altering a given variable in a given equilibrium situation. 3d.
4. Value the concept of equilibrium for its explanatory and predictive power.	4a. Choose to use the idea of equilibrium when appropriate for explaining a newly experienced phenomenon. 4b. Elect to make predictions in terms of equilibrium in an appropriate situation. 4c. Choose to continue to develop your concept of equilibrium. 4d.

Sample Test Questions

The sample evaluation items and their accompanying commentaries are intended to help illustrate the difference between concept-oriented learning outcomes involving the big ideas or major concepts in science and the more familiar content-oriented outcomes.

Question 1: ***A ticket line at a theatre was observed to have people leaving the line after purchasing their tickets, but the length of the line (number of people) remained the same. This situation could be described as an example of***

A. dynamic equilibrium.
B. static equilibrium.
C. a shift in equilibrium.
D. disruption of equilibrium.
E. cyclic behavior on the part of the people in line.

Commentary: This item is appropriate for assessing the level of development of the concept of equilibrium. In order to respond correctly, the student must be able to identify the situation described as an example of dynamic equilibrium (response "A"). This item would be appropriate for use with Sample Objective 2. In many disciplines, the appropriate application of the "dynamic equilibrium" requires that a closed system be involved. In cases where there is not a closed system, the expression "steady state" is utilized to describe the situation.

Question 2: ***Which of the following is not an example of an equilibrium condition?***

A. Plants living in a sealed container
B. A person maintaining constant weight
C. A 100-story office building
D. A burning piece of paper
E. A tug-of-war where the marker on the rope is not moving

Commentary: The concept-based question requires the learner to assess each possible choice to determine if it qualifies as an example of an equilibrium condition. Sample Objectives 1 and 2 could be assessed using this test item. The correct response is "D."

Question 3: ***Which question's answer will be most useful in determining whether or not an observed system is in static equilibrium?***

A. Is the system in equilibrium?
B. Is the system stable and balanced?
C. Are the observed changes occurring in equal amounts?
D. Are the observed changes occurring in opposite directions?
E. C and D

Commentary: This item is appropriate for assessing concept-based instruction. In order to respond correctly the student must differentiate static and dynamic equilibrium conditions and then identify the question most useful in determining if a yet to be observed system is in a state of static equilibrium. This test item could be used to assess Sample Objective 1. The correct response is "B."

Question 4: ***Please use the illustration below when selecting an answer.***

Fulcrum

What action(s) would not disrupt the equilibrium once the change(s) had been made?

A. Add mass at location 1
B. Add mass at location 3
C. Remove the fulcrum (support) and suspend the system from the ceiling by attaching a string at point 2
D. Reverse the masses that are located at positions 1 and 3 and leave everything else exactly as it is
E. C and D

Commentary: This concept-based test question requires the student to identify those elements of a given system that are important to the present equilibrium condition and then predict the result of altering one or more of those elements. The item is appropriate for assessing Sample Objective 3. The correct response is "C."

Question 5: ***Given the generic chemical reaction*** $A_{(g)} + B_{(g)} \rightleftharpoons C_{(g)} + D_{(g)}$ ***and the knowledge that the equilibrium constant is large*** $(K > 1)$,

A. the reaction proceeds from left to right to completion.
B. the reaction proceeds from right to left to completion.
C. no reaction will take place.
D. the reaction proceeds in both directions at the same very rapid rate.
E. temperature and partial pressures are needed in order to respond to this question.

Commentary: This question is NOT appropriate for the assessment of concept-based science instruction. Specific recall of content specific instruction (e.g., meaning of equilibrium constant "K") is required in order to knowingly respond correctly. While the detailed study of one example of equilibrium may well contribute significantly to the development of the concept, assessing the unique details of the example falls into the realm of topic-specific or content-specific evaluation.

For Further Information About Equilibrium

Encyclopedias

Exemplary Instructional Units

The Down-The-Hill Gang (Equilibrium). Cleveland, OH: Science Department, Educational Research Council of America, 1974 (grade 11).

US2. Seattle, WA: Science Department, Matteo Ricci College, 1977 (grades 10-11).

EVOLUTION

by David C. Cox
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Science Concept Working Paper #13 **Fall 1989**

Introduction

The concept "evolution" is unique among the major science concepts in two ways. First, it is very widely known, but unfortunately strongly tied to a single example of its application. In addition, that one example--the development of the various life forms on earth--has been the center of often volatile controversy. Due to this controversial connection, some people have been reluctant to apply the concept in other appropriate situations. This is unfortunate, since as is the case with the other major concepts, evolution is a powerful, broadly applicable concept with significant explanatory and predictive power.

The Concept

Evolution is any process of formation or development involving a series or pattern of slow changes over time. Therefore, evolution can be applied to serve as a general explanation of how something got to be the way it is or to predict what something may become. Evolution can be applied to the animate and inanimate, as well as to a host of other situations, such as activities, behavior and organizations. Some familiar examples should illustrate this breadth of application--the well-known evolution of the human species, the evolution of the airplane, and the evolution of drama.

The period of time involved in the evolutionary process is quite variable. One can identify evolutionary processes involving huge chunks of time on the human time scale, such as the millions of years involved in the evolution of a species, to those time spans that are considerably shorter, such as the evolution of the motion picture or our model for the atom. Of course, we must keep in mind that the process is probably still underway in all of these cases.

Another important consideration is the sequence or pattern of changes that enables us to identify situations where the concept evolution is applicable. The changes should indicate continuity in the formation or development of that object, characteristic(s), or other variable(s) that we identify as important. The key is that there be a steady tendency in a given direction. Think of the pattern involved, for example, in the evolution of bathing suits, television receivers, and cities.

When using evolution as an explanatory or predictive vehicle, one often needs to go beyond the identification of a sequence or pattern of change and begin to examine the mechanism controlling these changes. Experience shows that these can be natural (e.g., evolution of a landform) or human-driven (e.g., evolution of the computer). As a component of the natural system, humans are now often factors influencing what once may have been completely natural processes. Knowledge of the mechanism and influencing variables is extremely useful when extrapolating explanations or making predictions from the present. However, it is not necessary to understand the mechanism and important variables to make useful predictions and provide appropriate explanations.

People often indicate an interest in intervening in an evolutionary process to affect either the direction and/or rate of change. Typical examples would be the rapid production of "perfect" show plants and animals, protection of endangered species, and the preservation of the wilderness environment. Important ethical questions are raised by such potential interventions, and in addition, substantial knowledge of the change mechanisms and influencing factors is required if the desired effect is to be achieved.

Sample Instructional Objectives

From an instructional point of view, a concept takes on operational meaning when learner objectives are specified. The most meaningful concept development is likely to result from learning outcomes that address the concept in the most generalizable form possible. The sample objectives that follow are representative of a larger number that are particularly useful in promoting the understanding of and ability to appropriately apply the concept of evolution.

The objectives of this (lesson, unit, course, program) are for you to:	You will know that you are making progress when you can:
1. Increase your understanding of the concept of evolution.	1a. Operationally define evolution. 1b. Identify examples of evolutionary change involving animate and inanimate phenomena. 1c. When given several possible examples of evolutionary processes, correctly identify those that qualify. 1d. Differentiate evolution, change, order, and cycle. 1e. Critique someone else's definition of evolution. 1f.
2. Extend your ability to use the concept of evolution for explanatory purposes.	2a. Appropriately use the concept of evolution to explain a pattern of change that you had not experienced before. 2b.
3. Improve your skill at using the concept of evolution for making predictions.	3a. When given a new situation, predict the direction of evolutionary change. 3b. When given a newly experienced evolutionary phenomenon, predict either a past or future appearance of the object(s) of interest. 3c. When given randomly ordered stages in a newly experienced evolutionary process, correctly place the stages in order. 3d.
4. Increase your ability to identify factors influencing the direction and/or rate of evolutionary change.	4a. Identify examples of how humans have brought about changes in the direction and/or rate of evolutionary processes. 4b. Hypothesize regarding mechanisms involved in evolutionary change.

Sample Test Questions

The sample evaluation items and their accompanying commentaries are intended to further illustrate the difference between concept-oriented learning outcomes involving the big ideas or major concepts in science and the more familiar content-oriented outcomes.

Question 1: ***The phases of the moon are best explained as an example of***

A. a cyclic phenomenon.
B. change.
C. an evolutionary process.
D. a pattern.
E. an orderly arrangement.

Commentary: The concept-based item requires students to assess the appropriateness of several alternative general explanations of a commonly experienced phenomenon. The key differentiation is between cycle and evolution, and the deciding factor is probably the repeating nature of the phases of the moon at regular intervals, hence the correct response "A." This test item is appropriate for assessing Sample Objective 1.

Question 2: ***If the modern home refrigerator has evolved, which would be the most likely <u>just previous</u> stage?***

A. Underground storage
B. Box on a window sill
C. Icebox
D. Discovery of electricity
E. Invention of modern insulation

Commentary: This concept-based item requires students to separate contributing factors in the evolution of the refrigerator from the evolutionary stages themselves, and then order the given stages to identify the correct response "C." This question would be suitable for assessing Sample Objective 3 or 4.

Question 3: ***"Anything that changes slowly through time is evolving."***

This description of evolution

A. seems complete.
B. lacks the mention of *"continuity of change in one direction."*
C. needs to say that the changes are in *"living things and eventually result in a new species."*
D. is fine except that it needs to indicate that the *"changes occur at fixed time intervals."*
E. would be complete if it indicated that the *"time intervals involved are millions of years."*

Commentary: This item is suitable for assessing the degree of development of the concept evolution. In order to knowingly respond correctly, the student must be able to determine if there are any major shortcomings in the given statement, and if so, are they addressed in one of the choices provided. The correct response is "B." This item is suitable for assessing Sample Objective 1.

Question 4: ***At the present time, which is least likely to be able to be explained by the use of evolution?***

A. The origin of reptiles.
B. The appearance of the landscape.
C. Personal computers.
D. Atomic structure.
E. Today's television sets.

Commentary: This concept-based item requires students to determine the necessary criteria for the potential application of the concept evolution (e.g., trend of change through time, observation of earlier stages or evidence of their existence) and then establish which of the choices has the "poorest fit" to these criteria. The intended correct choice is "D." This item is suitable for assessing Sample Objective 2.

Question 5: ***Continuous genetic adaptation of an organism or species to the environment is achieved by means of***

A. selection.
B. hybridization.
C. inbreeding.
D. mutation.
E. All of the above

Commentary: This is not a concept-based test item. In order to respond correctly, a student must have experienced detailed instruction in one example of the application of evolution, and rather than generalize from that example, recall specific information regarding the mechanism responsible for change in that particular case.

For Further Information

FUNDAMENTAL ENTITIES

by David C. Cox
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Science Concept Working Paper #14 **Fall 1989**

Introduction

Atoms, cells, people, and bricks all have something in common. They are examples of basic components or "fundamental entities" useful in helping us understand and explain "things." The identification of fundamental entities is a critical step in our gaining an understanding of a wide variety of things, such as matter, living things, populations, and buildings.

The Concept

In the most straightforward sense, fundamental entities are basic units of structure and function. We are all familiar with examples of these key components. Some common science examples include bones (for the skeleton), chemical bonds (for molecules), molecules (for compounds), and stars (for galaxies).

The concept is applied equally appropriately outside science. Some examples are books (for libraries), words (for sentences), courses (for the curriculum), states (for the United States), and cells (for prisons).

The fundamental entities can be in contact (e.g., railroad cars in a train, links in a chain), separated (e.g., star and planets in a solar system, molecules in a crystal), or a combination of the two conditions (e.g., gaseous molecules, football players on a team, photons of light).

Sometimes the fundamental entities appear to be identical, as is the case with atoms of the same isotope and the quantity of charge on a single electron. In other cases, variation may exist; examples would be cells in living things, organisms in a population, isotopes of an element, and genes comprising a chromosome. It is also possible to have major differences between the fundamental entities comprising a phenomenon of interest. Examples of this situation would be the protons, electrons, neutrons, et al., forming atoms and the cell membrane, nucleus, et al., comprising living cells.

The identification of units serving as fundamental entities is a function of that which is being studied and the level at which it is being examined. Some units can serve as fundamental entities and themselves be composed of other fundamental entities. Examples of this would be molecules (fundamental entity is atoms), atoms (fundamental entities are protons, neutrons, etc.), chromosomes (genes are the fundamental entity), and genes (molecules are the fundamental entities).

Other major science concepts that appear to be closely related to fundamental entities include interaction, population, and system.

In summary, fundamental entities are identifiable basic "units," "structures," or "building blocks" that are useful in explaining phenomena. These fundamental entities can be units of structure and/or function. In addition, they can be in contact, separated, or exist in a combination of these two conditions. The fundamental entities may be identical, similar, different, or very different. Fundamental entities identified for purposes of one explanation may themselves be composed of other fundamental entities.

Sample Instructional Objectives

From an instructional point of view, a concept takes on operational meaning when learner objectives are specified. The most meaningful concept development is likely to result from learning outcomes that address the concept in the most generalizable form possible. The sample objectives that follow are representative of a larger number that are particularly useful in promoting the understanding of and ability to appropriately apply the concept of fundamental entities.

The objectives of this lesson, unit, course, program) are for you to:	You will know that you are making progress when you can:
1. Increase your understanding of the concept of fundamental entity.	1a. Operationally define fundamental entity. 1b. Critique a given definition of fundamental entity. 1c.
2. Extend your ability to recognize/identify fundamental entities.	2a. When given a list of "things" and another of "fundamental entities," correctly match items from the two lists. 2b. List at least three characteristics common to all fundamental entities. 2c. Identify some fundamental entities for things in your environment. 2d.
3. Increase your skill at using the concept fundamental entity.	3a. Briefly describe some explanatory and predictive benefits derived from the use of fundamental entities. 3b. Given a description and/or illustration of the fundamental entities characteristic of a "group of things," identify some of the members of the group. 3c. When given a collection of "things," classify the "things" into groups based upon identifiable fundamental entities. 3d.
4. Value fundamental entities for their explanatory and predictive power.	4a. Demonstrate a preference for explanations/predictions based upon the application of fundamental entities. 4b. Choose to appropriately use the concept fundamental entities when providing explanations and/or making predictions. 4c.

Sample Test Questions

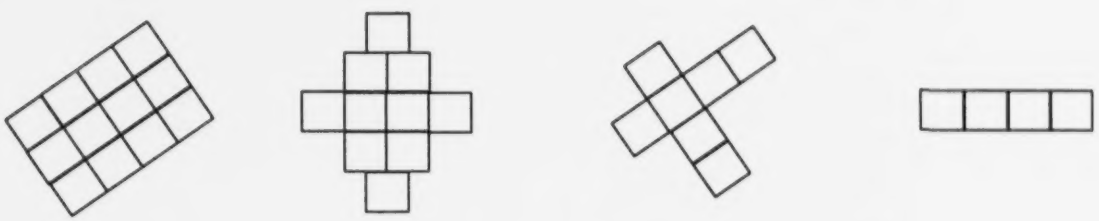
The sample evaluation items and their accompanying commentaries are intended to further illustrate the difference between concept-oriented learning outcomes involving the big ideas or major concepts in science and the more familiar content-oriented outcomes.

Question 1: ***Which is the fundamental entity most useful in describing the human skeleton?***

A. Atoms
B. Bones
C. Calcium
D. Levers
E. Molecules

Commentary: This concept-based question requires students to demonstrate their understanding of fundamental entity at several levels. Most significant decision making involves the choice between A, B and C, which are all potential fundamental entities. The correct choice, "B," requires the student to select the fundamental entity most appropriate for the given task. This item is appropriate for assessing Sample Objective 2.

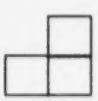
Question 2: ***Which is the common fundamental entity?***



A.

B.

C.

D. 

E. none of the above

Commentary: This concept-based item requires students to differentiate a common feature from the common fundamental entity of the figures. The correct choice is "A," and the item is appropriate for use with Sample Objective 2.

Question 3: ***Which is NOT a component of a typical living animal cell?***

A. cell wall
B. nucleus
C. mitochondria
D. cytoplasm
E. DNA

Commentary: This is not a concept-based questions, since it is asking for recall of detail regarding a particular fundamental entity. Correctly responding to this question does not necessarily indicate any aspect of the degree of development of the concept fundamental entity.

Question 4: ***Which pair does NOT reflect a fundamental entity--whole "thing" relationship?***

A. red color/automobile
B. water molecule/water
C. atoms/molecule
D. gene/chromosome
E. stars/galaxy

Commentary: This item can be considered concept-based if the learner is familiar with the vocabulary of the choices. If the vocabulary is in place, the item requires the student to apply his/her understanding of the concept to a variety of potential examples. The correct response is "A," and the item is suitable for use with Sample Objective 1.

For Further Information About Fundamental Entities

THEORY

by David C. Cox
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Science Concept Working Paper #15 **Fall 1989**

Introduction

The concept "theory" represents one of the most powerful explanatory and predictive vehicles in all of science. Examples of theory range from the widely known, such as Newton's universal theory of gravitation, Darwin's theory of evolution, cell theory, and continental drift, to the lesser know (but still important) such as the unified field theory, the theories of human color vision, conditioning theory of human behavior, and the theory of relativity.

While theory is often treated as synonomous with model, hypothesis, or educated guess, it in fact has a unique set of attributes that clearly differentiate it. To have a well developed concept of theory is the key to a richer, fuller understanding of and ability to apply those numerous scientific theories that form the exoskeleton of science.

The Concept

Science as a holistic enterprise is one human way of knowing (e.g., explaining, understanding, predicting, answering questions). Science has a number of explanatory/predictive tools, including facts, concepts, principles, generalizations, laws, models, and theories.

A theory represents the broadest level within science at which a scientist is likely to concentrate his or her effort. Theories are the basic or fundamental formal systems developed to account for observations. The better theories are simple, concise systems that serve as explanations for a large number of observations.

A theory consists of a set of interconnected statements relating to a certain aspect of the natural world. These statements can be in the form of words, symbols, mathematical equations or a combination of the three. The statements attempt to represent, in symbolic form, events that can be observed, those that are unobservable, and predict what will be observed under certain specific conditions.

In general, the statements that comprise theories are structured in the following manner.

1. First, the identification of the terms that are the basic theoretical entities. These terms are purposely left undefined. Examples of such terms are electron, positive charge, element, reinforcement, habit, bond, and nucleus.

2. Next, the specification of the relationships between the theoretical terms and the definition of any new terms.

3. Finally, the connecting of aspects of the theory to possible observations in nature. These statements are usually referred to as operational definitions or coordinating definitions. These are necessary in order for the theory to be meaningful.

Theories that have been accepted by the scientific community are generally quite well substantiated. In other words, they have been confirmed by considerable evidence and are more or less verified or established explanations accounting for known observations, facts, or phenomena. In addition, they suggest additional investigation. However, they are still tentative, incomplete, and subject to amendment, correction, and/or rejection. It is also important to keep in mind that theories can be confirmed or verified only to the present time and cannot be proven to be true in an absolute sense.

Theories are tested or confirmed by designing and conducting experiments based upon them, explaining observed events with them, and predicting from them what should be observed under specified conditions. Especially meaningful experiments or crucial experiments are those testing a prediction based upon a theory that is contrary to prevailing knowledge. If the confirming activity (e.g., experiment) has observations that have a positive match with the theory, the theory gains in power and status. If, on the other hand, there is no match, then there is an error somewhere in the theory, the interpretation of the system, or the methodology of observing.

It is also important to remember that theories are found in books, journals, and scientific papers, but not in nature. Theories are human-created systems useful in explaining some aspect of nature.

Other major science concepts that appear to be closely related to theory include cause-effect, evolution, interaction, model, probability, and system.

In summary, theories are the broadest scope devices created by humans to attempt to describe and explain observed and unobserved events and predict what may be observed under certain conditions in a particular domain of the natural world. When accepted for use and testing, they have been confirmed by considerable evidence. Theories are comprised of statements, both in words or other symbols, that identify the theoretical entities, relate these entities (including some created for the theory), and relate the system of statements to possible observations. Theories are tested by attempting to match their explanations, proposed observations, and predictions to the observations in the natural world. A method frequently employed for this purpose is the design and conduct of experiments based upon the theory.

Sample Instructional Objectives

From an instructional point of view, a concept takes on operational meaning when learner objectives are specified. The most meaningful concept development is likely to result from learning outcomes that address the concept i the most generalizable form possible. The sample objectives that follow are representative of a larger number that are particularly useful in promoting the understanding of and ability to appropriately apply the concept of theory.

The objectives of this (lesson, unit, course, program) are for you to:	You will know that your are making progress when you can:
1. Increase your understanding of the concept of theory.	1a. Operationally define theory. 1b. Differentiate fact, law, model, and theory. 1c. List at least three important contemporary scientific theories. 1d. Identify the major components of a scientific theory. 1e.
2. Extend your knowledge of the use of theories in science.	2a. Describe the role/purpose of theories. 2b. List several specific uses that can be made of theories. 2c.
3. Value theories for their explanatory and predictive power.	3a. Demonstrate a preference for explanations based upon accepted theories. 3b. Choose to extend your personal understanding of one or more theories of interest. 3c.
4. Increase your understanding of the ways in which theories are tested and confirmed.	4a. Describe at least three different ways in which a theory may be tested. 4b. Outline several possible implications of a "negative finding" when testing a theory. 4c.

Sample Test Questions

The sample evaluation items and their accompanying commentaries are intended to illustrate the difference between concept-oriented learning outcomes involving the big ideas or major concepts in science and the more familiar content-oriented outcomes.

Question 1: ***Which list of science explanatory "vehicles" is in decreasing order of scope?***

A. Fact, Model, Theory, Concept
B. Model, Concept, Fact, Theory
C. Theory, Model, Concept, Fact
D. Concept, Fact, Theory, Model
E. None of the above

Commentary: This concept-based item requires students to understand the scope relationships between a variety of explanatory "vehicles." The correct response is "C," and the item is suitable for use with Sample Objective 1.

Question 2: ***Which is most descriptive of a theory?***

A. Observations agreed upon by independent observers.
B. A tentative explanation for a specific natural phenomenon.
C. A confirmed fixed relationship between two or more variables.
D. The equivalent of a non-testable scientific hypothesis.
E. A set of interconnected statements accounting for observed and unobserved events in one domain of the natural world.

Commentary: This item requires students to evaluate a series of given statements to determine which has the best "fit" with the concept of theory. The correct response is "E," and the question is appropriate for use with Sample Objective 1.

Question 3: ***Theories are***

A. tested by designing experiments to validate predictions made from the theory.
B. basically correct, but require refining by the use of experiments.
C. assumed to be incorrect until proven to be true.
D. found in nature and discovered by humans.
E. A and C

Commentary: This concept-based item requires students to evaluate the appropriateness of several statements concerned with the nature of theories and the mechanism by which they evolve. The correct response is "A," and the question is suitable for use with Sample Objectives 1 and/or 4.

Question 4: ***Which is consistent with unified field theory?***

A. The proton is unstable.
B. Weak nuclear interaction is not a constant.
C. An average of one proton in a human being will decay during a lifetime.
D. A and C
E. A, B, and C

Commentary: This is not a concept-based question. While the item does deal with a theory, the focus is on understanding some specifics of a particular example. In order to respond correctly, the student would have had to have studied unified field theory and recalled selected information. A correct response in itself does not provide any evidence regarding the level of development of the concept of theory.

For Further Information About Theory

Karplus, Robert, et al. *SCIIS Scientific Theories Teacher's Guide*. Chicago: Rand McNally & Company, 1978.

McDain, Garvin and Segal, Erwin M. *The Game of Science*, Second Edition. Monterey, CA: Brooks/Cole Publishing Company, 1973.

MODEL

by David C. Cox
Portland State University

Science Concept Working Paper #16 **Fall 1989**

Introduction

The scientific concept "model" may operationally be the most pervasive concept cutting across the various science disciplines, and therefore one of the most powerful for learners to develop. Not only are scientific models used as explanatory and predictive tools within the science disciplines, but science textbooks and other instructional materials are literally loaded with them.

The development of the concept of scientific model both increases the student's personal level of scientific literacy and lays the foundation for an enhanced level of meaningful learning in science. Since scientific models play a central role in the scientific enterprise, an adequately developed concept of model is essential for an understanding and appreciation of the scientific "way of knowing."

The Concept

Scientific models are tentative, human-made schemes or structures which seem to correspond to real "things" or phenomena. Put in somewhat simpler terms, scientific models are our best idea as to the composition and "workings" of something of interest. Our explanations for electricity, magnetism, the stars, learning, and the behavior of volcanoes, for example, are all based upon models.

Scientific models are created when the phenomenon or object of interest cannot be observed directly in sufficient detail to provide a full and complete descriptive explanation. We often rely on models when the object or phenomenon of interest is too large (e.g., the earth), too small (e.g., atoms), too distant (e.g., the stars), or removed in time (e.g., the origin of the earth).

Some examples of commonly used scientific models that are often, unfortunately, treated as if they were descriptive fact, are the structure and composition of the earths interior (remember the nicely labeled cross-sectional views that you've seen in texts), the Rutherford-Bohr model for the atom, the inheritance of traits (ah yes, Mendelian genetics), the description of our solar system (yes, really), the nature of light, and the composition of and manner by which energy is generated within our sun and the other stars.

It is especially important not to confuse the physical models (e.g., scale or replica models of real objects or models constructed to illustrate scientific models) with the idea or construct that is the scientific model. For example, a world globe that can be separated into two hemispheres containing labeled cross-sectional views of the structure and composition of the interior of the earth is intended to illustrate our model for the interior of the earth. However, since many other models used in science teaching are scale or replica models of real things, there is a tendency to treat the globe described above as a scale model of the real thing. The spirit, value, meaning, and open-endedness of the scientific model is lost under such treatment.

Much of the highly creative work within the scientific community involves the making and testing of predictions based upon the current population of accepted scientific models. Scientific models may change, or evolve, when new or improved observations are made and/or predictions based upon the models are tested and found to be in disagreement. In some rather unusual but dramatic cases, the anomalies resulting from new observations or the testing of predictions can cause a model to be replaced (e.g., heliocentric replacing geocentric "world" system, wave model replacing particle model for light). However, the more usual situation is to adjust or modify the current model so that it can accommodate the new observations. In mature scientific disciplines, a working collection of accepted models for various phenomena of interest is considered to be a desirable state of affairs.

In summary, scientific models are a scientific discipline's best "guess" as to the composition of something and the interaction between its elements and with its environment. Scientific models are needed when the object or phenomenon of interest cannot be adequately observed directly. We use scientific models both to provide tentative explanations and as a basis for generating testable predictions.

Sample Instructional Objectives

From an instructional point of view, a concept takes on operational meaning when learner objectives are specified. The most meaningful concept development is likely to result from learning outcomes that address the concept in the most generalizable form possible. The sample objectives that follow are representative of a larger number that are particularly useful in promoting the understanding of and ability to appropriately apply the concept of scientific model.

The objectives of this (lesson, unit, course, program) are for you to:	You will know that you are making progress when you can:
1. Increase your understanding of the concept of model as it is used in science.	1a. Select the examples of scientific models from a list of possibilities. 1b. List several examples of scientific models. 1c. Write your own definition of a scientific model. 1d. List some common characteristics of scientific models. 1e. Explain the differences between scale models and scientific models. 1f.
2. Improve your model development skills.	2a. Design at least one test to help validate a given scientific model. 2b. Develop a beginning model for a newly observed phenomenon. 2c. Critique someone else's model for a given phenomenon. 2d.
3. Further your ability to test the validity of models.	3a. Describe in your own words the process used for validating scientific models. 3b. Identify from a list those tests which would be useful for validating a given scientific model. 3c. Make at least two testable predictions that would be useful in validating a given scientific model. 3d.
4. Expand your knowledge of the limitations of scientific models.	4a. Cite an example of a situation where two or more different models can be used to explain the same phenomenon. 4b. Cite examples of models that have been replaced or modified. 4c. List at least three limitations common to all scientific models. 4d.

5. Extend your understanding of the role of scientific models.	5a. Describe the role or purpose of models in science. 5b. Differentiate fact, opinion, model, and theory. 5c.
6. Extend your knowledge of the ways in which models evolve or change.	6a. Describe at least two general reasons that any given model may change. 6b. Cite examples of models that have been replaced or modified. 6c.
7. Value scientific models for their explanatory and predictive power.	7a. Demonstrate a preference for explanations based upon accepted scientific models. 7b. Choose to use a scientific model when making predictions regarding a phenomenon. 7c. Choose to develop a model for explaining a new phenomenon. 7d.

Sample Test Questions

The sample evaluation items and their accompanying commentaries are intended to help illustrate the difference between concept-oriented learning outcomes involving the big ideas or major concepts in science and the more familiar content-oriented outcomes.

Question 1: ***Which is the best example of a scientific model?***

A. World globe
B. Working model of a steam engine
C. Map of the United States
D. Plastic skeleton containing all of the bones in the human body
E. Nuclear fusion as responsible for the energy from the sun

Commentary: In order to correctly respond to this item, the student must bring to bear substantial conceptual understanding. The student must be able to differentiate between replica models, scale models, physical models, and scientific models. An awareness of the type of phenomena requiring scientific models is also necessary. This question represents an appropriate concept oriented item suitable for use in measuring the degree of achievement of Sample Objective 1. The correct response is "E."

Question 2: ***Scientific models are used primarily for***

A. illustrating important facts.
B. providing tentative explanations.
C. summarizing known facts.
D. expressing the opinions of individual scientists.
E. communicating information to the nonscientific public.

Commentary: This sample question is assessing student understanding of the model concept. To respond correctly requires students to understand the general purpose/role of models in science. It would represent an appropriate concept-oriented item for assessing Sample Objective 5. The correct response is "B."

Question 3: ***Which of the following are limitations of scientific models? (Select all correct choices.) Scientific models are***

A. unable to provide absolute explanations.
B. based on opinion.
C. based on observations.
D. not able to be tested or challenged.
E. useful only to scientists.

Commentary: This is a question suitable for assessing a student's understanding of the concept of model. The student must know the general bases from which models are constructed, be cognizant of their tentative nature, and be familiar with the mechanism and potential for change in order to respond correctly. No specific content area recall is required. This item would be appropriate for assessing Sample Objective 4. The correct response is "A" and "C."

Question 4: ***Sketch the Rutherford-Bohr model for the hydrogen atom and label all components.***

Commentary: This question is asking for detail regarding one example of a scientific model. The focus is not on the concept of model, but on the details of the Rutherford-Bohr model for the hydrogen atom. If the desired learning outcome is to have students develop an understanding of the Rutherford-Bohr model, the question is acceptable, albeit low level. It is, however, a "content" rather than concept-oriented question. A student could respond correctly to this item and have little or no development of the concept of model.

Question 5: ***The animal "x," black coat color is due to a dominant gene (B), and white coat color is due to the recessive allele (b). If a homozygous black male is crossed with a heterozygous black female, what phenotype distribution would you predict?***

A. 100 percent black coats
B. 50 percent black coats and 50 percent white coats
C. 25 percent black coats and 75 percent white coats
D. 75 percent black coats and 25 percent white coats
E. 100 percent white coats

Commentary: This is a "content" oriented question. The student is required to recall certain critical vocabulary (e.g., homozygous, heterozygous, phenotypes) and then apply the given information according to predetermined rules. A student could respond correctly to this item and not even realize that a scientific model was involved. If content specific information must be recalled in order to successfully respond to a test item, it is not a concept-oriented item at the desired level of generalizability.

For Further Information About Model

Exemplary Instructional Units

The Guessing Game. Milwaukie, OR: Science Department, Rex Putnam High School, 1985 (grades 9-10).

US2. Seattle, WA: Science Department, Matteo Ricci College, 1977 (grades 10-11).

PERCEPTION

by David C. Cox
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Science Concept Working Paper #17 **Fall 1989**

Introduction

The concept of "perception" relates to a process that we nearly continuously engage in without the benefit of much conscious thought or reflection. The same is true in the science classroom, where the concept receives little formal attention. Perception is crucial, however, since it is concerned with the origin of our individual "world view" or operational physical reality, which is the starting point for most formal and informal science learning experiences.

The Concept

Perception in a straightforward sense is a package deal, involving the detection of input signals by the senses, transmission of these signals or messages to the brain, and the interpretation of these signals by the mind. In other words, perception is our individual connection to the "real" world; it is the process by which we create physical reality from sensory input.

If any one of the three components (sensory detection, transmission, or interpretation) is missing, we have no perception. In addition, a number of factors influence our perception. Perhaps foremost among these factors is experience. Since individuals differ in total experience, individuals can perceive the same environmental stimulus differently.

Our differences in perception of the same stimulus are sometimes masked by associating certain descriptors with certain perceptions. For example, a group of people can be exposed to a stimulus object and be told that it is "red." Without awareness of the similarities and differences in individual perceptions, we collectively learn to associate the descriptor with the perception, and we communicate the experience as red. This gives the appearance of a common perception--which may or may not be true. Put another way, does everyone perceive "red" the same? Or, from a science point of view, does it matter if everyone perceives red the same? Let's move beyond the learned or shared association situation and ask another question. What happens to people's ability to communicate regarding the external world if the perception is being experienced for the first time? How do we explain a common phenomenon that is perceived differently by different observers? The perception issue is further complicated by the fact that many, if not most, environmental events are complex and stimulate several different senses.

The tentative nature of our perceived reality is often brought to our attention by means of optical illusions that we experience. Some of these illusions occur naturally, while others are "created" by the artist or skilled professional performer. The illusions need not be limited to the visual.

Do we have ways to check or validate our perceptions? Certainly we do, but that still doesn't eliminate the uncertainty of our perceptions. One commonly used procedure is to share perceptions with other observers. Our communication skills and the limitations of our language become important here, but the process certainly facilitates agreement. Another procedure is to utilize measurement, although this is not always practical. The application of logical thought is another aid in the perception clarification process.

In summary, perception is the meaning we give to sensory input that has been transmitted to the brain. Many factors influence perception, with experience perhaps being the most important. Acknowledgment of the tentative nature of our individual perceptions of the "world" is an important dimension of scientific literacy.

Sample Instructional Objectives

From an instructional point of view, a concept takes on operational meaning when learner objectives are specified. The most meaningful concept development is likely to result from learning outcomes that address the concept in the most generalizable form possible. The sample objectives that follow are representative of a larger number that are particularly useful in promoting the understanding of and ability to appropriately apply the concept of perception.

The objectives of this (lesson, unit, course, program) are for you to:	You will know that you are making progress when you can:
1. Increase your understanding of the concept of perception.	1a. Operationally define perception. 1b. Differentiate perception and fact. 1c. Explain the role of the sense organs in perception. 1d. Critique a given definition of perception. 1e.
2. Extend your knowledge of the factors that influence perception.	2a. List instruments that could be used to extend or supplement the senses. 2b. Explain the role of the variation in sensory acuity to perception. 2c. List at least three factors influencing perception. 2d. Give examples of situations where a change in sensory input changes perception. 2e. Explain the role of experience in perception. 2f.
3. Develop your ability to test or validate perception.	3a. Describe the potential value of discussing your perceptions with independent observers of the same phenomena. 3b. Resolve ambiguous or conflicting perceptions by measuring. 3c. Apply logical thought to the clarification of perceptions by linking to past experience. 3d.

Sample Test Questions

The sample evaluation items and their accompanying commentaries are intended to further illustrate the difference between concept-oriented learning outcomes involving the big ideas or major concepts in science and the more familiar content-oriented outcomes.

Question 1: ***Which is NOT necessary in order for perception to occur?***

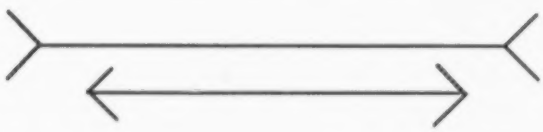
A. A sensory stimulus.
B. Detection by the senses.
C. Transmission of a signal to the brain.
D. Interpretation by the brain.
E. Prior experience with the same stimulus.

Commentary: This item is appropriate for assessing a student's development of the concept perception. The selection of "E" as the correct response requires the differentiation of the conditions/elements necessary for perception and factors that influence perception. This test item could be used for assessing student progress towards achieving Sample Objective 1 or 2.

Question 2: ***If you are in a room and hear no sound, which statement is most descriptive?***

A. The room is empty.
B. There are no sounds in the room.
C. You do not perceive any sound in the room.
D. It is quiet in the room.
E. The room has been made sound proof in order to eliminate noise from the outside.

Commentary: This concept-based item is designed to determine if the student is able to analyze the role of perception as the connection between an observer and the environment. Selection of "C" as the correct response requires a knowledge of the limitations of the senses and the individual uniqueness of perceptions. This item is appropriate for use in assessing Sample Objective 1.



Question 3: ***Two students were observing the lines above and disagreed as to which line was longer. Which would be most useful in resolving their conflicting perceptions?***

A. Ask some other students which line they think is longer.
B. Have the entire class observe the two lines and vote.
C. Ask the teacher which line is longer.
D. Cover up the arrowheads and then compare the length of the two lines.
E. Measure the length of the two lines.

Commentary: This concept-based test item addresses the resolution of conflicting perceptions and asks students to select the most useful approach from a list of several viable alternatives. The desired response ("E") is the most appropriate choice, even though several of the others may produce the same final resolution. This item is appropriate for assessing Sample Objective 3.

Question 4: ***Perception is influenced by***

A. the prior experiences of the perceiver.
B. the number of senses involved.
C. the limitations of the senses involved.
D. B and C.
E. A, B, and C.

Commentary: This straightforward concept-based item requires students to demonstrate their awareness of some of the factors influencing perception. The intended correct response is "E." This item is appropriate for assessing Sample Objective 2.

Question 5: ***Typical human visual reaction time is closest to***

A. 0.001 s
B. 0.01 s
C. 0.1 s
D. 0.5 s
E. 1.0 s

Commentary: This is not an appropriate concept-based test item. Even though the item deals with a related topic, the ability to respond correctly depends upon certain information having been previously supplied and now recalled. There is no necessary connection between the ability to correctly respond to this item and an understanding of and ability to apply the concept of perception.

For Further Information About Perception

Exemplary Instructional Units

Educational Research Council of America. *Perceiving My World.* (secondary) Cleveland, Ohio: Educational Research Council of America, 1971.

Science Department, Rex Putnam High School. *Is Your World My World?* (grades 9-10) Milwaukie, Oregon: Rex Putnam High School, 1976.

SYMMETRY

by David C. Cox
Portland State University

Science Concept Working Paper #18 **Fall 1989**

Introduction

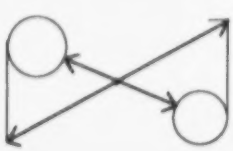
The notions of harmony, balance, similarity, proportion and arrangement seem to combine uniquely to capture the broad meaning of the concept of "symmetry." We've all used the concept in a variety of ways (e.g., cutting out paper figures such as stars, pumpkins and hearts, explaining why the left hand of a mirror image moves when we move our right hand, expressing why a building, pattern, etc. seems pleasing). While symmetry is often perceived as pleasing (e.g., architecture, farmland viewed from the air, formal gardens), it is sometimes purposely avoided (e.g., composing a photograph, creating the unexpected perception).

Symmetry seems to play an important role in art, mathematics, music, and a host of other seemingly divergent areas. The concept of symmetry is also widely used in science. In fact, a powerful explanatory and predictive skill is to be able to see or "feel" symmetry where others have failed to perceive it. Symmetry is certainly a concept whose increased development will enhance the intellectual/perceptual power of learners.

The Concept

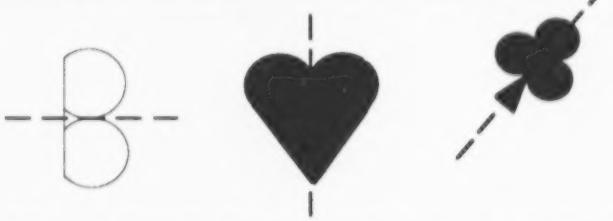
The idea of symmetry is somewhat simply captured by the thought of arrangement in accordance with a certain similarity (i.e., balance). For many situations, this similarity can be in reference to a point, a line or a plane.

When the symmetry is relative to a point, it is referred to as spherical, rotational, central, or point symmetry, depending upon the particular example. The point itself is referred to as the center of symmetry or point of symmetry. Any straight line through this point will find "sameness" at equal intervals out from the point in both directions. A few common examples are snowflakes, many crystals, rectangles and wheels. The examples that follow should further illustrate this type of symmetry.



If the symmetry is relative to a line or plane (imagine the line or plane to be like a mirror whose reflection forms the other half of the "thing"), it is generally referred to as reflective or bilateral symmetry (e.g., both halves the same). With younger learners, this type of symmetry is often called mirror symmetry or mirror balance. The line is known as the axis of symmetry, and the plane is referred to as the plane of symmetry. Mathematically speaking, the axis of symmetry would be the reference for two dimensional figures, and the plane of symmetry used for three dimensional situations. There can be one or more axes or planes of symmetry present. A cube, for example, has 4 planes of symmetry (1 horizontal, 1 vertical, and 2 along diagonals).

Some common examples are the external human body, "valentine" hearts, the letter A, and a butterfly. The examples below may help further clarify the idea.



A type of symmetry known as radial symmetry is closely related. In this radial symmetry condition, the sameness of structure occurs around a central axis. This term is frequently used in biology when making reference to such animals as sea anemones and jelly fishes.

It is also important to note that things can simultaneously possess several types of symmetry. A snowflake, for example, has both reflective (bilateral) and rotational (point) symmetry.

There are, of course, nonspatial applications of symmetry, such as time reversal, color complements, and black/white inversions. Things that do not possess the attributes of symmetry are referred to as asymmetrical.

Closely related major science concepts include equilibrium, fundamental entities, interaction, invariance, order, organism, perception and resonance.

Sample Instructional Objectives

From an Instructional point of view, a concept takes on operational meaning when learner objectives are specified. The most meaningful concept development is likely to result from learning outcomes that address the concept in the most generalizable form possible. The sample objectives that follow are representative of a larger number that are particularly useful in promoting the understanding of and ability to appropriately apply the concept of symmetry.

The objectives of this (lesson, unit, course, program) are for you to:	You will know that you are making progress when you can:
1. Increase your understanding of the concept of symmetry.	1a. Operationally define symmetry. 1b. Identify examples of at least two different types of symmetry. 1c. Differentiate point, bilateral, and radial symmetry. 1d. Critique a definition of symmetry. 1e.
2. Expand your ability to recognize symmetry.	2a. When given a collection of things (e.g., objects, pictures), identify those that possess symmetry. 2b. When given a group of symmetrical "things" and a list of types of symmetry, correctly match the "things" to the types of symmetry. 2c.
3. Extend your ability to apply the concept of symmetry.	3a. Appropriately use the concept of symmetry when making observations. 3b. When given that a particular type of symmetry is present and appropriate starting information, use the concept in making predictions. 3c.
4. Value the concept of symmetry for its predictive and explanatory power.	4a. Choose to further develop your personal concept of symmetry. 4b. Choose to use the concept of symmetry when making observations, formulating explanations, and/or making predictions. 4c. Value explanations and predictions based upon an appropriate application of the concept of symmetry. 4d.

Sample Test Questions

The sample evaluation items and their accompanying commentaries are intended to further illustrate the difference between concept-oriented learning outcomes involving the big ideas or major concepts in science and the more familiar content-oriented outcomes.

Question 1: ***Which is most descriptive of the concept symmetry?***

A. Repeating a pattern at regular time intervals
B. Balance between opposing forces or tendencies
C. In order by increasing size, weight, etc.
D. Increasing or decreasing at a more or less regular rate
E. Arrangement or condition that has perceived balance

Commentary: This high level, concept-based question requires students to evaluate each of several descriptive statements in terms of a "match" with their concept of symmetry. The distractors generally describe the related concepts of cycle, equilibrium, order, and gradient. The correct response is "E," and the item is suitable for use with Sample Objective 1.

Question 2: ***Which has at least two different types of symmetry?***

A.

B.

C.

D.

E.

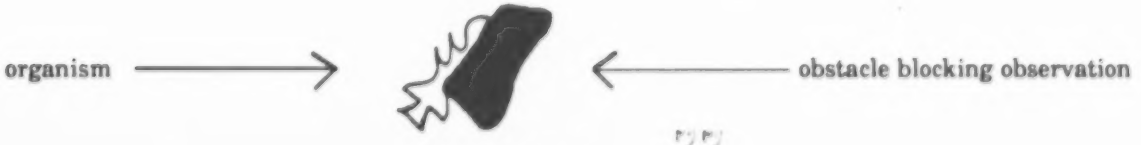
Commentary: This concept-based question directs the student to apply his/her understanding of the types of symmetry to several "things." The distractors all possess only one form (although there may be several axes) of symmetry. The correct response is "D," which has both point and bilateral symmetry. This item is appropriate for use with Sample Objective 2.

Question 3: ***Which organism(s) display radial symmetry?***

A. human being
B. snake
C. sea anemone
D. drosophila
E. all of the above

Commentary: This is NOT an example of a concept-based question. While the item is concerned with the concept of symmetry, the learner must recall prior information in order to knowingly respond correctly. The primary reason for this is that even if radial symmetry is understood, only the names of organisms are provided. Unless these names can be connected with a type of symmetry, there is no basis for choice (e.g., the structure of the organisms is not illustrated).

Question 4: **An organism is known to have bilateral (reflective) symmetry. Part of such an organism is observed as illustrated.**



The "hidden" portion of the organism is probably most like:

A.

B.

C.

D.

E.

Commentary: This concept-based question requires students to apply their understanding of symmetry by making a prediction. The correct response is "C," and the item is suitable for use with Sample Objective 3.

For Further Information About Symmetry

Illustrated reading for students and teachers:

Kim, Scott. *Inversions*. Peterborough, NH: BYTE Books, 1981.

FIELD

by David C. Cox
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Science Concept Working Paper #19 **Fall 1989**

Introduction

Explanations of such diverse observations as a satellite orbiting the earth, the turning of a compass needle, and the operation of a television picture tube all utilize the concept of "field." While these examples are rather sophisticated science uses, the concept also has applications in everyday situations. We can talk about something being in our field of view, one nation being within the field or under the influence of another, or the temperature field surrounding or within the earth.

It is important for the contemporary citizen to develop an understanding of and ability to apply the concept of field in order to deal effectively with explanations and predictions involving action-at-a-distance as well as a variety of other phenomena.

The Concept

In the most general sense, a field is a region or space where measurable values of some variable exist. The field is usually named after the variable of interest (e.g., force field, temperature field, pressure field).

There are two categories or classes of fields. One category is known as scalar fields, while the other is referred to as vector fields. In a scalar field, the variable whose values comprise the field has magnitude (i.e., size) only. Examples of such fields would include the temperature field surrounding the earth, various pressure fields, density fields and sound fields.

Vector fields are comprised of measurements of variables that require both a magnitude and a direction in order to be completely described. Examples of such fields include force fields (e.g., gravitational, electric) and velocity fields.

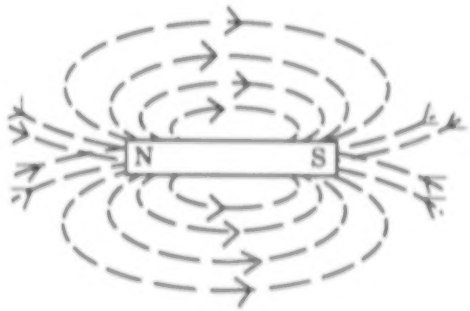
Fields are quantified by measuring the value of the variable at a variety of locations. In fact, the operational limits or boundaries of a field are established by this ability to measure. Where values for a field can be predicted by the use of a mathematical relationship (e.g., force field), a test or measurement must be made before it is known for sure that the field does exist in that location. An illustration showing values for the variable at a variety of locations is often referred to as a map of the field.

One of the most frequent applications of the field concept is in the form of a force field. Force fields are regions of interaction or influence established by a source. The specific force field is named for the type of "thing" that is influenced by or interacts with the field. The three most common force fields are the gravitational, which influences matter; electric, which influences electric charge; and magnetic, which influences magnetized "things."

Contemporary findings indicate that a changing electric field can influence magnetized "things" and that a changing magnetic field can influence electric charge, but such extensions of the idea are beyond the scope of this paper.

The path that an interacting "thing" follows in a force field is known as a line of force, and collectively, these lines of force are often used to map these fields for purposes of describing their "shape." The sketches that follow illustrate a partial application of this technique for two common examples.

Magnetic Field Near a Bar Magnet
(Lines of Force / Flux Trace the Path of an Independent North Pole)



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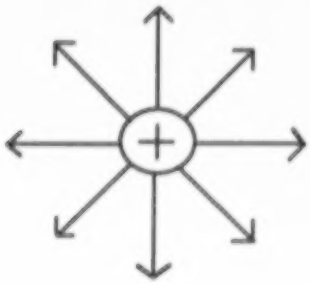
Electric Field Near a Charged Object
(Lines of Force Trace the Path of an Independent Positive Charge)



Two or more fields of the same or different type can occupy the same space at the same time. If something is influenced by more than one of these fields, the interactive effects are all experienced. In the case of force fields, the effects are additive.

Closely related major science concepts include cause-effect, change, equilibrium, force, gradient, and interaction.

Sample Instructional Objectives

From an instructional point of view, a concept takes on operational meaning when learner objectives are specified. The most meaningful concept development is likely to result from learning outcomes that address the concept in the most generalizable form possible. The sample objectives that follow are representative of a larger number that are particularly useful in promoting the understanding of and ability to appropriately apply the concept of field.

The objectives of this (lesson, unit, course, program) are for you to:	You will know that you are making progress when you can:
1. Increase your understanding of the concept of field.	1a. Operationally define the concept field. 1b. List examples of the application of the concept of field. 1c. Correctly list the defining attributes of field. 1d. Differentiate scalar and vector fields. 1e. Differentiate field, gradient, interaction and force. 1f. Critique a description of the concept field. 1g.
2. Improve your ability to use the concept of field.	2a. Identify situations where the use of the field concept is appropriate. 2b. When suitable, explain a newly experienced phenomenon using the concept of field. 2c. Predict the result of placing a given "thing" in a designated field. 2d.

3. Extend your ability to quantify fields.	3a. Operationally define field strength. 3b. When given appropriate data or observations, calculate the field strength. 3c. When given suitable information, predict the interactive force acting on a given object in a given field. 3d.
4. Value the concept of field for its explanatory and predictive power.	4a. Choose to further develop your personal concept of field. 4b. Value explanations and predictions based upon the appropriate application of the concept of field. 4c. When warranted, choose to use the concept of field. 4d.

Sample Test Questions

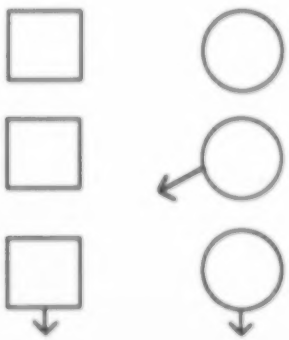
The sample evaluation items and their accompanying commentaries are intended to illustrate the difference between concept-oriented learning outcomes involving the big ideas or major concepts in science and the more familiar content-oriented outcomes.

Question 1: ***A field***

A. occupies a region of space.
B. contains measurable values for a variable.
C. is a region of influence or interaction.
D. A and C
E. A, B, and C

Commentary: This concept-based item assesses a learner's knowledge of the attributes that define fields. The correct response is "E," and the item is suitable for use with Sample Objective 1.

Question 2: ***Two objects are placed near each other and released. They are both at rest at the time they are released. The arrows indicate movement in the direction of the arrow. Which observation does NOT provide evidence of one or more fields?***

A. 

B.

C.

D.

E.

Commentary: This concept-based item is concerned with recognizing situations where the use of the concept of field is appropriate. They key idea is to identify evidence of interaction at a distance. The correct response is "A," and the item is appropriate for use with Sample Objective 2.

Question 3: ***Which is closest to the magnitude of the gravitational field strength on the surface of the earth's moon?***

A. 0.0 newtons/kilogram
B. 0.17 newtons/kilogram
C. 1.6 newtons/kilogram
D. 9.8 newtons/kilogram
E. 60.0 newtons/kilogram

Commentary: This is NOT an example of a concept-based question, even though a field is the primary focus. A correct response provides no evidence of the level of development of the concept of field. In order to respond correctly, the student must recall specific information regarding one application of the concept.

Question 4: ***Which is NOT a general attribute of a force field?***

A. Influences selected "thing(s)"
B. Has a source
C. Has a region of interaction
D. Has weight and takes up space
E. Provides a way of explaining some phenomena

Commentary: This concept-based item is concerned with identifying the attributes of force fields. The correct response is "D," since fields are not assigned the attribute of mass. The question is suitable for use with Sample Objective 1.

For Further Information About Field

GRADIENT

by David C. Cox
Portland State University

Science Concept Working Paper #20 **Fall 1989**

Introduction

The concept of "gradient," which is extremely valuable for its explanatory and predictive power, is representative of many situations that we have experienced. Some common examples are the sloping ramp leading into a building or stadium, the ear-popping evidence of pressure changes as we ascend or descend in an airplane, and the temperature changes experienced as we go deeper into the water of a pool or lake.

The Concept

Albeit overly simplified, a gradient may be thought of as the situation where a measurable, variable quantity (e.g., temperature, pressure, density, elevation) is increasing or decreasing at a more or less regular rate. Examples are surprisingly common and include such diverse phenomena as the regular increase in water pressure with depth, the more or less steady increase in temperature as one drills down into the earth, the highway that climbs a hill at a steady rate, and the density change of water as it is layered at different temperatures. Gradients can occur through either space or time.

Gradients are expressed in terms of the rate of change of the variable of interest. These expressions can carry such units as $^{o}C/km$, $^{o}C/hr$, $n/m^2/km$, $g/cm^3/^{o}C$, and m/km to express temperature, pressure, density, and elevation gradients. Gradients are often portrayed graphically, and the value of the gradient in such cases is found by calculating the slope (e.g., rise/run) of the graph.

Gradients do not have specified minimum dimensions, such as distance intervals, temperature ranges, or time intervals for the varying quantities. The operational criteria for determining if the application of the gradient concept is appropriate is if it will serve a useful purpose for either explaining or making predictions relative to the phenomenon of interest.

The predictive power is especially interesting, since predictions can take several dimensions. The predictions may be interpolations (values between known values), extrapolations (values beyond known values), or even "road maps" to the location of the source of some phenomena (e.g., radio wave source traced by following the gradient of increasing intensity).

Major science concepts closely related to gradient include cause-effect, change, cycle, energy-matter, evolution, field, interaction, invariance, order, perception, quantification, scale, and time-space.

Sample Instructional Objectives

From an instructional point of view, a concept takes on operational meaning when learner objectives are specified. The most meaningful concept development is likely to result from learning outcomes that address the concept in the most generalizable form possible. The sample objectives that follow are representative of a larger number that are particularly useful in promoting the understanding of and ability to appropriately apply the concept of gradient.

The objectives of this (lesson, unit, course, program) are for you to:

1. Increase your understanding of the concept gradient.

You will know that you are making progress when you can:

1a. Operationally define gradient.
1b. Differentiate change, gradient, order, and scale.
1c. Critique a given description of gradient.
1d.

2. Increase your ability to identify gradients.	2a. List several examples of gradients. 2b. When given a series of graphs, identify those that depict gradients. 2c. Determine if the data in a given data table represent a gradient. 2d.
3. Expand your ability to make predictions using gradients.	3a. When given a graph illustrating a gradient, predict a value or change in value for a specified condition. 3b. When given a data table representing a gradient, predict a value or change in value for a specified condition. 3c.
4. Value the concept of gradient for its explanatory and predictive power.	4a. Choose to use gradient as a way of explaining a newly experienced phenomenon. 4b. Demonstrate a preference for explanations and predictions based upon the appropriate application of the concept gradient. 4c.
5. Improve your ability to quantify gradients.	5a. When given a graph portraying a gradient, calculate the value of the gradient and express it with appropriate units. 5b. Correctly interpret the meaning of a given value for a gradient. 5c.

Sample Test Questions

The sample evaluation items and their accompanying commentaries are intended to illustrate the difference between concept-oriented learning outcomes involving the big ideas or major concepts in science and the more familiar content-oriented outcomes.

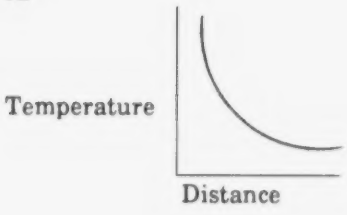
Question 1: ***A student described the concept gradient as "a situation where the temperature is increasing at a regular rate." The student's statement***

A. adequately describes the idea of gradient.
B. should not restrict gradients to temperature changes.
C. should not restrict gradients to increases in a measurable quantities.
D. should indicate that gradients occur through distance.
E. B and C

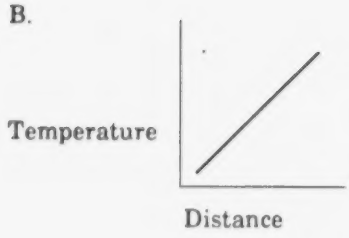
Commentary: This concept-based item requires the reader to evaluate several basic portions of a statement attempting to describe the concept gradient. The particular choice made will provide useful insight into the level of development of the idea, with the highest state of development indicated by the choice of "E." This item is suitable for use with Sample Objective 1.

Question 2: ***Which depict(s) "gradient?"***

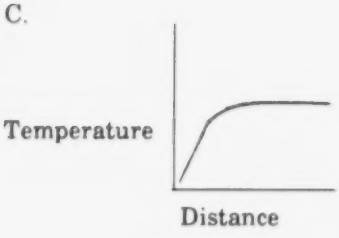
A.



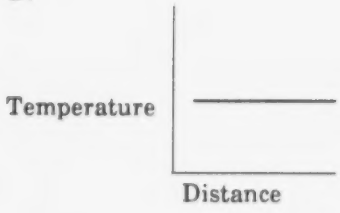
B.



C.



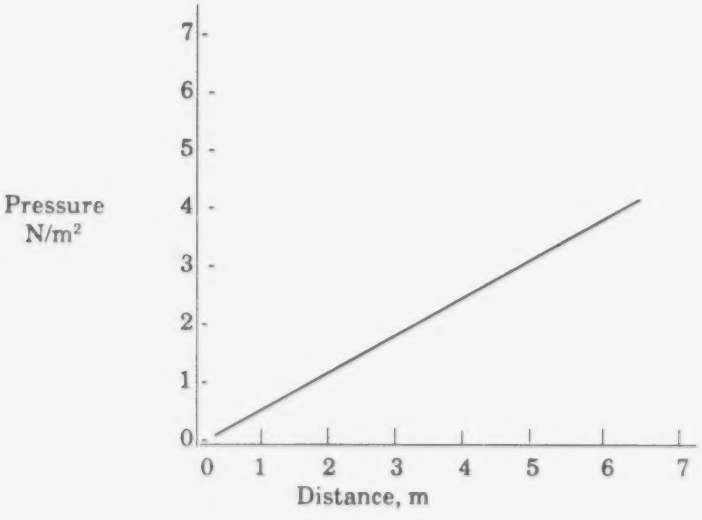
D.



E. A and B

Commentary: This is a concept-based item assuming that the prerequisite graphing skills and knowledge are in place. The reader is required to first determine if change in a measurable quantity is depicted, and if so, if it is occurring at a regular rate. The best answer is "E," and the test item is appropriate for use with Sample Objective 2.

Question 3:



At a distance of 8 meters, what would be the predicted pressure?

A. 0 N/m^2
B. 3 N/m^2
C. 4 N/m^2
D. 8 N/m^2
E. No prediction can be made due to inadequate information.

Commentary: This item is concept-based, even though it is dependent upon some graphing skills being in place and could be responded to correctly without knowingly applying the concept gradient. In order to respond correctly, the reader identifies the existence of a gradient and then extrapolates with the value of the gradient (0.5 $n/m^2/m$). The correct response is "C," and the item is suitable for use with Sample Objective 3.

Question 4: ***A temperature gradient of 2.5°C/km has been identified. This means that***

A. in the distance studied, the temperature was increasing at a rate of 2.5°C/km.
B. in the distance studied, the temperature was decreasing at a rate of 2.5°C/km.
C. over a total distance of 1 km, the temperature was measured to have changed by 2.5°C.
D. the temperature is changing by 2.5°C during the time that it takes to travel 1 km along the gradient.
E. A or B

Commentary: This concept-based question assesses the learner's understanding of the meaning of a quantitative expression of a gradient. Choices "C" and "D" are clearly incorrect, since "C" assumes a total distance of 1 km was studied and "D" indicates that the temperature is changing as a function of time rather than distance. Based upon the information provided, the best response is "E." The question is suitable for use with Sample Objective 5.

Question 5: ***What is the average value of the earth's geothermal gradient?***

A. 1.0°C/km
B. 5.0°C/km
C. 13.0°C/km
D. 20.0°C/km
E. 30.0°C/km

Commentary: This is NOT a concept-based test item. While the question is concerned with gradient, recall of specific information regarding one example of a gradient is required in order to respond correctly. Recalling the value of the earth's geothermal gradient provides no insight into the level of development of the concept of gradient.

For Further Information About Gradient

Suggested Improvements

Fill out this form with your comments, fold and return by mail to address printed on back side.

Concept Paper #	Corrections, Additions Deletions, Comments, Questions

Place
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Attention: Ray Thiess

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